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Land Application of Sewage Sludge Under Adverse Conditions

Research Report No. 53

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under Provisions of the Canada-Ontario Agreement
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RESEARCH REPORTS

These RESEARCH REPORTS describe the results of investigations funded under the Research Program for the Abatement of Municipal Pollution within the provisions of the Canada-Ontario Agreement on Great Lakes Water Quality. They provide a central source of information on the studies carried out in this program through in-house projects by both Environment Canada and the Ontario Ministry of the Environment, and contracts with municipalities, research institutions and industrial organizations.

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LAND APPLICATION OF DIGESTED SLUDGE UNDER ADVERSE CONDITIONS

by

Pollution Control Division
Public Works Department
The Regional Municipality of Niagara

RESEARCH PROGRAM FOR THE ABATEMENT
OF MUNICIPAL POLLUTION WITHIN THE
PROVISIONS OF THE CANADA-ONTARIO
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ABSTRACT

This study involved the disposal of sludge on land which, because of continual periods of rain or spring melting conditions, had become impassable to normal sludge hauling vehicles (tank trucks). The reasons for this concern were:

(1) the deterioration of the sewage treatment plant effluent quality if sludge removal cannot be carried out for an extended period, and
(2) the cost of sludge holding facilities in adverse conditions.

Initially, two separate literature reviews were conducted:

(1) The first was made to determine current equipment used in sludge application to land and to assess potential problems associated with the equipment to be tested. Little written information was available on this topic and it was necessary to obtain data by personal communication.
(2) Agricultural literature on soil compaction was reviewed to determine the effects of vehicular traffic on soil.

Five vehicles (a tank truck, a sludge injector, a bulldozer, a front-end loader and an all-terrain vehicle) were field tested and evaluated. The tank truck was used as a control vehicle; the bulldozer and front-end loader were tested because of their availability rather than any inherent qualities which lend themselves to sludge spreading; the sludge injector and all-terrain vehicle had been used with a great deal of success previously for sludge disposal on land. A system for sludge spraying was also investigated.

Soil compaction analyses, crop analyses, problems experienced, and breakdowns encountered during spreading were used as parameters for evaluation. None of the vehicles investigated proved ideally suitable and effective in the spreading of sludge on wet soils.

Spraying of sludge proved to be the most suitable method for land application under certain weather conditions but was suitable only for well-screened sludge. The sludge injector was judged as the vehicle which caused minimal field damage in terms of compaction under the wheels

and, therefore, most appropriate for land disposal of sludge where ploughing was to follow the application on forage or fallow crops. However, it left deep ruts in the clay soil, where the injector device failed to properly refill the furrows and showed a number of operational problems. While in operation, the ploughing apparatus frequently plugged up with sod and dirt, making it necessary to stop the operation and clear the obstructions. The sludge injector system was also prone to miring and was ineffectual in hard or frozen ground.

RÉSUMÉ

La présente étude a porté sur l'épandage de boues résiduaires dans des conditions de pluies prolongées ou de fonte printanière rendant le terrain impraticable aux véhicules transportant ordinairement les boues (camions-citernes). Les impératifs commandant cette étude étaient:

1) la détérioration de la qualité des effluents des usines d'épuration lorsque les boues ne peuvent être enlevées pendant une période prolongée,
2) le coût d'accumulation des boues attribuable à des conditions défavorables.

Au départ, cela a donné lieu à deux études bibliographiques distinctes:

1) La première visait à déterminer le type d'équipement servant couramment à l'épandage des boues et à évaluer les problèmes que pouvaient présenter les engins à éprouver. Il n'existait que très peu de documentation là-dessus; on a dû compléter les renseignements par des communications personnelles.
2) La seconde a porté sur les publications intéressant l'agriculture et, notamment, sur le tassement du sol sous les roues des véhicules.

Cinq véhicles (un camion-citerne, un injecteur de boues, un bulldozer, un chargeur à benne frontale et un véhicule tout-terrain) ont fait l'objet d'une évaluation sur place: le camion-citerne servait de témoin; quant au bulldozer et au chargeur, c'est leur utilisation généralisée plutôt que leur efficacité reconnue pour épandre les boues qui en a suggéré l'essai; l'injecteur et le véhicule tout-terrain s'étaient déjà révélés efficaces. Un dispositif d'aspersion a également été mis à l'épreuve.

Les analyses de tassement du terrain, les études de cultures ainsi que les problèmes et les pannes survenus au cours de l'épandage ont servi de fondement à l'évaluation. Aucun des véhicules ne s'est révélé parfait pour l'épandage sur terrains détrempés.

L'aspersion a été la méthode la plus appropriée à certaines conditons météorologiques, mais elle ne convenait qu'aux boues finement tamisées. Parmi les véhicules, l'injecteur a le moins tassé le terrain; on l'a donc jugé le mieux adapté à d'épandage sur fourragères ou jachères

s'accompagnant de labour. Toutefois, il a laissé des ornières profondes dans le soil argileux, qui ne permettait pas au dispositif d'injection de remplir convenablement les sillons, et il a connu un certain nombre de problèmes de fonctionnement. L'appareil de labourage, fréquemment obstrué par l'herbe et le sol, a nécessité de nombreux arrêts. De plus, le dispositif d'injection s'embourbait facilement et était inefficace sur les sols durs ou gelés.

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CONCLUSIONS

(1) None of the vehicles or methods investigated proved to be ideally suitable and effective. It is probable that there is no single simple solution, and any choice made for a particular situation, at best, will be a compromise between effective sludge spreading and minimal difficulties.

(2) The bulldozer type vehicle was too slow and heavy and caused excessive damage to the topsoil and turf.

(3) The front-end loader was too cumbersome and also caused excessive field damage.

(4) Spreading was too slow with the all-terrain vehicle and it also caused field damage.

(5) The sludge injector caused the least field damage, but frequently clogged with sod and was ineffective in hard soil.

(6) The tank truck also caused minimal field damage but became easily mired, in which case it then caused excessive field damage.

(7) Sludge spraying was the most effective system in mild and calm conditions and with well-screened sludge.

1 INTRODUCTION

One of the effluents of a municipal sewage treatment process is sewage sludge. Generally, this is anaerobically digested at 95°F for 30 to 45 days. Fortunately, digested sewage sludge is of value for its fertilizer and soil conditioning qualities. For this reason, and because of its relatively low cost, the most widely used method for disposal of digested sewage sludge in Ontario is through land application by tank truck. Increasing urbanization is making this less attractive, especially for major cities. Several problems are associated with the practice of land application of digested sewage sludge, principally that during the autumn and spring months when soils are soft and wet, as a result of precipitation and thawing of snow and frost, conventional sludge hauling vehicles are unable to drive over the fields without becoming mired or causing excessive rutting and compaction of the soil. Consequently, sludge storage facilities are required until such times as field conditions do not impede the spreading of sludge by tank truck. Storage can be provided in the digesters but is limited in most cases. Also of concern is the effect on the treatment plant if sludge removal cannot be carried out for an extended period. The volume and solids content of the digester supernatant, which is returned to the treatment process, increases and can cause organic overloading. The digesters also may become upset through overloading.

This study was carried out on the assumption that the fertilizer and soil conditioning values of digested sludge are best utilized in field crops as opposed to other methods of disposal, such as landfilling or incineration.

The intent of this study was to test and evaluate various types of vehicles and to determine their suitability for spreading sludge on fields under adverse conditions.

2 OBJECTIVES

The objectives of this study were to:

1) determine the suitability of various types of tracked vehicles and low pressure wheeled vehicles to the spreading of sludge on wet soils;
2) determine the effect of using injectors in applying sludge to the land, especially to frozen ground;
3) determine the effect on crops of the various means of application outlined above; and,
4) evaluate the effectiveness of sludge spraying as a means of sludge application to land.

3 CURRENT EQUIPMENT USED IN LAND APPLICATION OF SLUDGE

3.1 Kitchener Pollution Control Plant

The sludge from the Kitchener plant is spread onto the land. Some of the digested sludge from the Kitchener Water Pollution Control Plant is discharged to three sludge drying lagoons, totalling 20 acres, at the plant site. After a period of approximately two years, the sludge moisture content has been reduced from about 95% to about 15% through natural drying. The lagoons are emptied by a front-end loader and the dried sludge placed into dump trucks, which carry the sludge to the spreading site. The sludge is spread on the land by a tractor driven manure spreader, or spread directly onto the ground from the trucks. The ground is ploughed within 24 hours by a tractor pulled plough or tiller. No problems have been encountered using this method.

Most of Kitchener's digested sludge is spread in liquid form on agricultural land by one of two methods. In the first method a truck with a 3000 Imp gallon capacity tank is filled at the plant and is driven to the spreading site. The tank is pressurized and the sludge is sprayed out the back approximately 30 feet high and 60 feet wide. In adverse weather the truck becomes mired. In the second method a 4500 Imp gallon capacity tractor-trailer transports the sludge from the plant to the site. Here it is transferred into a 3000 Imp gallon capacity tractor-pulled tank trailer. The sludge is sprayed out the back in a strip 30 to 40 feet wide. The farmers on whose land this is carried out have no complaints about this method adversely affecting crops, but equipment is prone to miring in extremely adverse weather.

3.2 South Peel Pollution Control Plant

At the South Peel Water Pollution Control Plant two sludge lagoons are maintained for the dumping of sludge during adverse conditions, usually during November and December when frost in the ground prevents land application. The lagoons are emptied by tank trucks in which a vacuum is created to draw the sludge into the tank, and the sludge is ejected out the back of the truck using a pressurized system. Attempts have been made to spread the sludge with gravity spreaders on the back of trucks, but this has proved unsatisfactory because of uneven application.

When the lagoons are not used the sludge is taken directly from the digesters, put into pressurized tank trucks and then taken directly to the fields and sprayed from the rear. These trucks leave ruts, compact the soil and often get stuck in wet fields. One contractor for the South Peel Pollution Control Plant tried to use a large "flex tract" vehicle with a 4000 Imp gallon capacity tank. Mechanical problems with this vehicle (not related to spreading sludge) resulted in its use being discontinued. However, when it was in use during the spring, it left ruts in the fields, reportedly one to two feet deep, but never bogged down. The ruts were unacceptable for crop land.

3.3 Regional Niagara Pollution Control Plants

Under contract, the sludge from the Region's pollution control plants is handled in a similar manner to that used by the Kitchener and South Peel contractors. Sludge lagoons are maintained for times when land application is impossible due to adverse conditions. The tank trucks often bog down in the fields and leave undesirable ruts. Because the tanks are not pressurized, but rely on gravity to empty, unequal distribution of sludge results. The current contractors also have a sludge injector system which consists of a tank, a pump and an injector unit. As the injector is pulled across the field by a tractor, a trench is made into which the sludge is forced and covered with soil. The sludge injector eliminates excessive rutting (although adverse soil conditions may prevent proper closure of the furrow), the need for ploughing after spreading, and odour problems (if the injector is used for animal manures, as design intended, or for poorly digested sludges). Problems described later preclude the frequent use of this piece of equipment.

3.4 Ministry of the Environment Project Operations Branch

Mr. M. Bell of the Project Operations Branch of the Ministry of the Environment has stated that similar methods to those outlined above are used by other Ministry operated plants and the same problems have been encountered. Gravitational flow trucks with splash plates on the rear to spread the sludge are used. Bad weather conditions force the trucks to halt spreading.

3.5 Conclusions

All areas in Ontario appear to have similar problems in the disposal of sludge when land application is the method of disposal. There is a definite requirement for equipment that will perform in the fields like the flex-track vehicle, but will leave no ruts and deliver the sludge efficiently into the ground like the sludge injector. Ordinary pressurized tanks seem to be too vulnerable to adverse weather conditions to be practical in the spreading of sludge. If suitable equipment could be developed, the cost of lagooning and dependence on weather conditions could be eliminated.

4 SOIL COMPACTION

Soil is a porous body composed of particles separated by voids (pores). The size of these voids is a result of size, shape and packing arrangement of the particles. Soils may contain particles of a very wide variety of dimensions, from fractions of a millimeter to several centimeters. Particles may be of a number of different shapes, mostly irregular. The arrangement of soil particles is never strictly regular and uniform.

The porosity of soil (i.e. total volume of voids between particles) varies from 20-58%, reaching 85% in peaty soils.

Compaction occurs by the reorientation of the particles or the distortion of the particles and their absorbed layers. Static pressure is not very effective in this process, as the grains wedge against each other and resist movement. If the grains can be momentarily freed, then even light pressure is effective in forcing them into a more dense arrangement.

Water flow will reduce the particle friction and permit easier compaction. However, water in the voids also prevents the particles from assuming a more dense arrangement. For this reason, water is effective in stopping compaction in fine grained soil where water cannot leave the voids quickly.

Forces in soil can be classified into two broad categories - internal and external. Internal forces are those that originate within the soil mass, freezing, drying and swelling being sources of internal forces. External forces are those supplied to some boundary of the soil mass. These forces include buildings, vehicles and tillage tools.

Vehicles unquestionably comprise the primary source of compaction. Tillage implements themselves are sources of external forces. In general, implements which cause the soil to move tend to produce localized compaction. Blunt cutting edges, high coefficients of friction or adhesion at the soil-metal sliding interface, and improper rake angles can produce compactive forces.

It has been proved that tractor tires cause considerable compaction immediately below the tires. The depth of penetration of compaction effects increases with initial looseness of the soil and the moisture content. Peak compaction occurs at moisture contents near the lower plastic limit, which is about the optimum condition for tillage.

Compacted regions found below plow depths are commonly referred to as tillage pans. The compression of the tractor tire extends below plow depths and, for this reason, tillage pans cannot be eliminated by plowing at conventional depths.

Research results on the depth of tillage pans in relation to soil moisture are given in Figure A1 (Appendix I). The amount of compaction in relation to soil moisture may be seen in Figure A2. The dry cecil clay was compacted to 20% less than its original volume; moist clay was compacted 53% and wet clay 49%.

Extensive research was carried out in 1962 by Vanden Berg and Gill to determine the stress pattern under a dynamically loaded wheel. Pressure patterns were obtained from transducers in several types of soils. The data in Figure A3 indicates that the pressure patterns are influenced by the conditions of the tire. Not indicated in Figure A3, but of importance, was the effect of soil conditions on the pressure patterns. In general, as the soil was softer and compacted more, the magnitude of the pressure was less.

Compaction may inhibit or even prohibit shoot and root growth. Soil density and plant growth are both directly related to soil moisture. Also of importance is the fact that root growth can be restricted by increasing soil density. The rate of movement of water through soil affects the entry of water into soil, the movement of water to plant roots and the evaporation of water from the soil surface.

Root penetration into soils of high bulk density is dependent on soil moisture content. Provided that aeration is not limiting, roots often penetrate a soil layer of high density when the moisture in that layer is relatively high, but as this layer dries out its density may prohibit root penetration.

Tillage pans restrict corn root penetration, probably because of physical resistance to root growth, a reduction in soil oxygen and because there are too few crevices through which the roots can grow.

In conclusion, compaction is detrimental to shoot and root growth The compaction of soil results, primarily, from externally applied forces and the primary source of these forces is vehicular traffic.

5 SLUDGE SPREADING REPORT

5.1 Introduction

From July to October, 1973, a literature review, site requisition, equipment rentals and other preparatory work were undertaken.

A 20 acre site on the outskirts of Port Colborne was donated by the St. Lawrence Seaway Authority. Figure A4 shows the location of the site.

Spreading of sludge began in late October and early November of 1973. In all, there were five sludge applications to the study site, each using a different vehicle. The vehicles were chosen as being alternate means of locomotion that could be adaptable to tank installation. Subsequently, sludge spraying and frozen soil injection were investigated.

During the course of each spreading, samples of sludge and soil were obtained for analysis. A sample of the sludge to be spread was sent to the University of Guelph for analysis of N, P, K, Ca, Mg, Mn, Cu, Zn, B, solids content and pH. Soil samples were analyzed by Mr. D. Summers, for determination of moisture content and density of compacted and uncompacted soil. The results of both these tests are presented in Tables 1 and 2.

In order to determine whether the sludge applied would affect the soil composition, soil samples were obtained on October 31, 1973 and sent to the University of Guelph for analysis. The results are shown in Table 3. The locations of the soil analysis sites are found in Figure A5.

The test site was divided into five plots whose dimensions were 100 by 500 feet, thus yielding an area of 1.15 acres. Figure A6 gives a layout of the test site. Since the study area was relatively flat (less than 1% slope), separating ditches or dykes to prevent runoff were not required. The land was basically characterized as clay and clay loam (see Table 4), which is representative of a good portion of the Niagara Region and of southern Ontario. The location of drilling sites for textural classification are marked in Figure A7.

The spreading dates, plot numbers and vehicles employed are summarized in Table 5.

The tank truck served as the control, as this is the most common disposal method currently used in Ontario.

TABLE I. SEWAGE SLUDGE ANALYSIS

Vehicle	N %	P %	K %	Ca %	Mg %	Mn ppm	Cu ppm	Zn ppm	B ppm	pH	% Dry Matter
Tank Truck	.158	.097	.015	.158	.035	10	51	63	1	7.0	4.7
ATV	.163	.06	.014	.107	.027	6	40	58	1	7.2	3.3
Sludge Injector	.202	.075	.018	.134	.036	8	23	46	1	7.7	3.7
Bulldozer	.209	.075	.018	.136	.037	7	20	44	1	7.7	3.6
Front-End Loader	.209	.075	.022	.138	.038	8	21	47	1	7.8	3.7

TABLE 2. COMPACTION TEST RESULTS

Plot Number and Vehicle	Uncompacted Soil Field Wet Density (lb/cu ft)	Moisture Content %	Field Dry Density (lb/cu ft)	Compacted Soil Field Wet Density %	Moisture Content %	Field Dry Density (lb/cu ft)
1 Tank Truck	110	37.7	80	121	39.9	86.5
2 ATV	86.4	37.0	63.0	103	37.0	75.4
3 Sludge Injector	95.5	33.4	71.5	103	33.6	77.2
4 Bulldozer	90.5	38.2	66.5	113	36.4	83
5 Front-End Loader	98	45.7	67.5	97	45.7	66.5
6 Sludge	-	44.6	-	N.A.	N.A.	N.A.

N.A. - Since no use was made of equipment, no compaction resulted, therefore, no analyses were done.

TABLE 3. SOIL ANALYSIS TEST RESULTS

Sample Number	Phosphorus ppm	Potassium ppm	pH	Magnesium ppm	Texture
1	11	292	5.7	576	Clay and Clay Loam
2	10	244	5.5	544	Clay and Clay Loam
3	9	188	5.5	480	Clay and Clay Loam
4	7	204	5.4	432	Clay and Clay Loam
5	9	240	5.8	640	Clay and Clay Loam
6	6	160	5.6	528	Clay and Clay Loam

TABLE 4. FIELD TEXTURAL CLASSIFICATION OF SOIL

Hole Number	Depth	Textural Classification
1	0 - 5 1/2" mix	Clay Loam
	at 2"	Medium Clay
	at 12"	Silty (medium) Clay
	at 26"	Light Clay
2	"Top Soil"	Clay Loam
	11" - 21"	Silty (medium) Clay
	at 36"	Silty Clay
3	0 - 5 1/2"	Clay Loam
	at 14"	Silty Clay
	13" - 18"	Silty Clay
	at 29"	Silty Clay
4	at 4"	Silty Clay
	at 25"	Silty Clay
	at 35"	Silty (medium) Clay

Note: Above classifications from "Guide for Soils Field Inspector" - D.H.O. Manual Properties Observed; visual appearance polish, cast, ribbon and feel.

TABLE 5. DATE, PLOT, VEHICLE DATA

Date	Plot Number	Vehicle Employed
Nov. 1, 1973	1	Tank Truck
Nov. 2, 1973	2	All-terrain Vehicle
Nov. 5, 1973	3	Injector
Nov. 8, 1973	4	Crawler Bulldozer
Nov. 9, 1973	5	Front-end Loader
Jan. 22, 1974	6	Injector

5.2 Weather Conditions

Pertinent weather data are tabulated in Table 6 for the days of application and sampling and for adjacent dates. Table A1 shows weather for January, 1974 and compares the monthly precipitation during 1973 to the average precipitation.

The Niagara Region receives 30 to 35 inches of rainfall annually. The precipitation pattern results in relatively high soil moisture content (see Figure 1) during the spring and fall when the precipitation is the greatest. As indicated in the soil compaction literature review, high soil moisture content magnifies the compacting effects caused by vehicles.

During the test period the weather was typical, although the rainfall totalled 4.55 inches in October, as compared to an average rainfall of 2.62 inches for this month. Field conditions which were expected for mid-fall resulted.

Any conclusions and recommendations made are based on weather and soil conditions typical to the Niagara Penisula. These may, however, be applied to areas with similar conditions.

5.3 Vehicles and Equipment

The main objective in this project was to determine the suitability and effectiveness of various vehicles in applying sewage sludge to wet soils. In order to make this evaluation, it was necessary to have some knowledge about the operation and specifications of the means of sludge application.

5.3.1 Tank truck

By far the vehicle most often used in sludge spreading is a conventional tank truck. Such a truck may be equipped with a vacuum pump. In order to load sludge into the tank on the vehicle, the pump creates a vacuum in the tank and thus draws in the sludge. Alternately, sludge is pumped into the truck with equipment installed at pollution control plants for this purpose. Emptying the tank is normally effected by either of two ways: the pump on the truck may pressurize the tank, consequently forcing the sludge out; or unloading may be accomplished by simple gravitation flow. The latter method does not require a pump, but it does not result in uniform spreading.

TABLE 6. WEATHER DATA ON SLUDGE APPLICATION DATES AND ADJACENT DATES

Date	High Temperature (^oF)	Low Temperature (^oF)	Precipitation (inches)	Wind Direction	Wind Velocity (mph)	Observations
Oct. 31/73*	55	47	.11	SW	7	
Nov. 1/73*	51	42	.22	W	18	Cloudy with clear intervals
Nov. 2/73*	55	42	.33	SW	9	Clear, sunny
Nov. 3/73	48	40	nil	W	16	
Nov. 4/73	43	37	nil	NW	13	
Nov. 5/73*	43	30	nil	W	13	Clear, cold with traces of snow on the ground
Nov. 6/73	38	29	Trace of snow	W	18	
Nov. 7/73	42	29	nil	W	11	
Nov. 8/73*	49	32	nil	W	16	Clear, cold with some snow on ground
Nov. 9/73*	37	26	.40	W	13	Cold with light snow flurries
Nov. 10/73	36	26	Trace of snow	NW	10	
Jan. 22/74*	36	32	.50 snow .25 rain	W	11	Overcast, cold with drizzle and light melting snow

* Dates of application

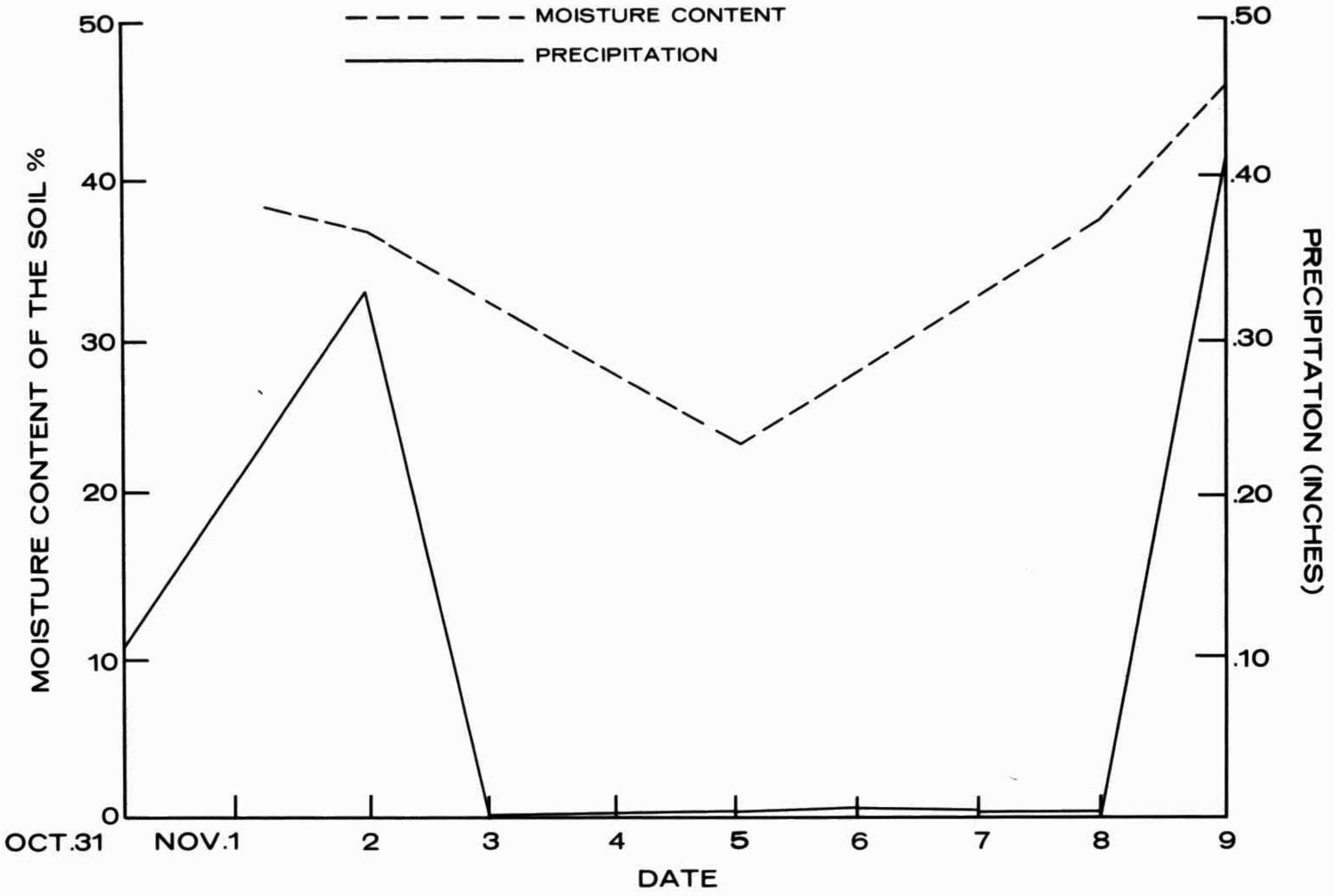


FIGURE 1. SOIL MOISTURE CONTENT AND PRECIPITATION

Tank capacities vary, but the truck used in this study was rated at 2200 Imp gallon capacity. There were no modifications made to the truck or tank and, being the conventional method, it served as a control. The truck was equipped with a vacuum pump; however, the gravity flow method was used for emptying. (See Figure 2.)

5.3.2 Injector

Several manufacturers produce specialized equipment for sludge and liquid manure application, consisting of a tanker on wheels that is equipped with an injector. The machine used in this study was manufactured by Clay Equipment Corporation, Iowa. It operates in three stages. It is equipped with toothed ploughing wheels which open dual trenches in the soil. Flexible tubes and rigid conduits at the rear of the injectors direct the sludge from the tanker into the soil opening. The tank is pressurized and injects the sludge continuously, approximately 7 - 8 inches deep into the opening. A pair of spring-loaded paddles mounted behind each injector serve as a soil-covering device.

The injector is not motorized and must be towed, usually by a farm tractor. The tractor also controls the tank pressure and position of the plough apparatus by means of hydraulic hook-ups. Both the tractor and the injector must be transported by float if the travel distance is substantial.

The particular injector used in the study had a 750 Imp gallon capacity tank. (See Figure 3.)

5.3.3 Temporary holding tank

The remaining vehicles used in the sludge application were not specialized for this purpose. As a result, there was, initially, no means of holding or spreading the sludge. This problem was solved by mounting a 250 Imp gallon capacity tank into convenient locations on the various vehicles.

It was necessary to modify the tank slightly so that it might be used effectively. A 2" diameter valve was installed on the tank, and brackets and chains were used to hold the tank in place on the different vehicles. Due to the location of the valve, the tank, which emptied by gravity flow, did not drain completely and approximately 30 gallons were left in the tank each load.

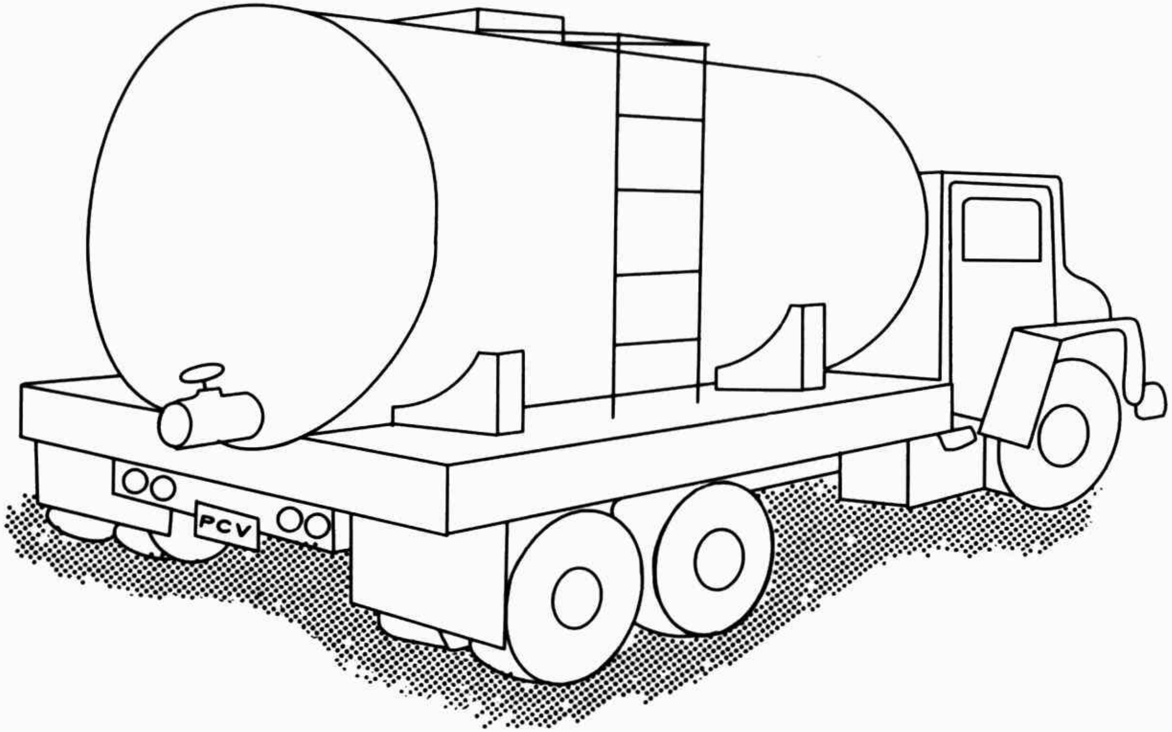


FIGURE 2. TANK TRUCK

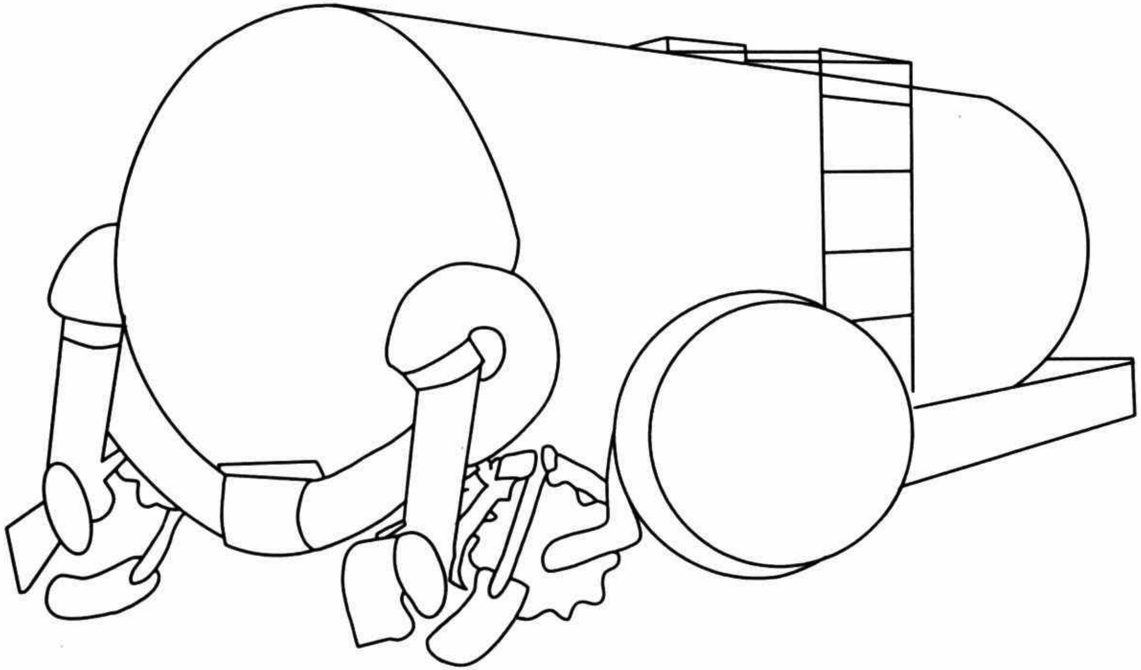


FIGURE 3. SLUDGE AND LIQUID MANURE INJECTOR

5.3.4 All-terrain vehicle

An all-terrain vehicle, or ATV, was one of the machines equipped with the tank. The ATV simply consisted of an enclosed operator's cab mounted at the front of the flat bed which ran on a pair of wide tracks. The holding tank was mounted on the flat bed of the ATV, and a splash plate was positioned below the effluent valve of the tank.

The St. Lawrence Seaway Authority loaned the vehicle and the driver. The ATV requires float service if it is to be moved significant distances (See Figure 4.)

5.3.5 Bulldozer

Another vehicle used in the study was a conventional crawler bulldozer. It was necessary to float the bulldozer to the site and chain the temporary holding tank into the bucket. This bulldozer was an old model which locked the inside track in order to turn. On newer models the inside track reverses, thus effecting a faster turn and less damage to the ground surface. (See Figure 5.)

5.3.6 Front-end loader

A four-wheel drive, rubber-tired, front-end loader was also used in the study. The temporary tank was chained inside the bucket. This vehicle required no float service. (See Figure 6.)

5.3.7 Sludge spraying

Other equipment under experimental use for sludge application was a system for spraying sludge much like conventional farm irrigation. This system consisted of sludge being pumped from a tank truck through pipes to irrigation sprinklers.

Four-inch diameter standard aluminum irrigation tubing was used. Rigid aluminum tubing is preferred over flexible hose because it is less expensive and lighter. Connections were easily made and were free from leaks because a rubber gasket in the connection expanded with the pressure in the system, thus effecting a leak-proof joint.

The pump was manufactured in Britain by White-Rain Company. To run the pump, power may be supplied by the drive train of a farm tractor, car or truck engine having a horsepower rating of at least 65 hp. A gear box was incorporated in the pump unit to achieve the proper pump speed, which was approximately 1500 revolutions per minute.

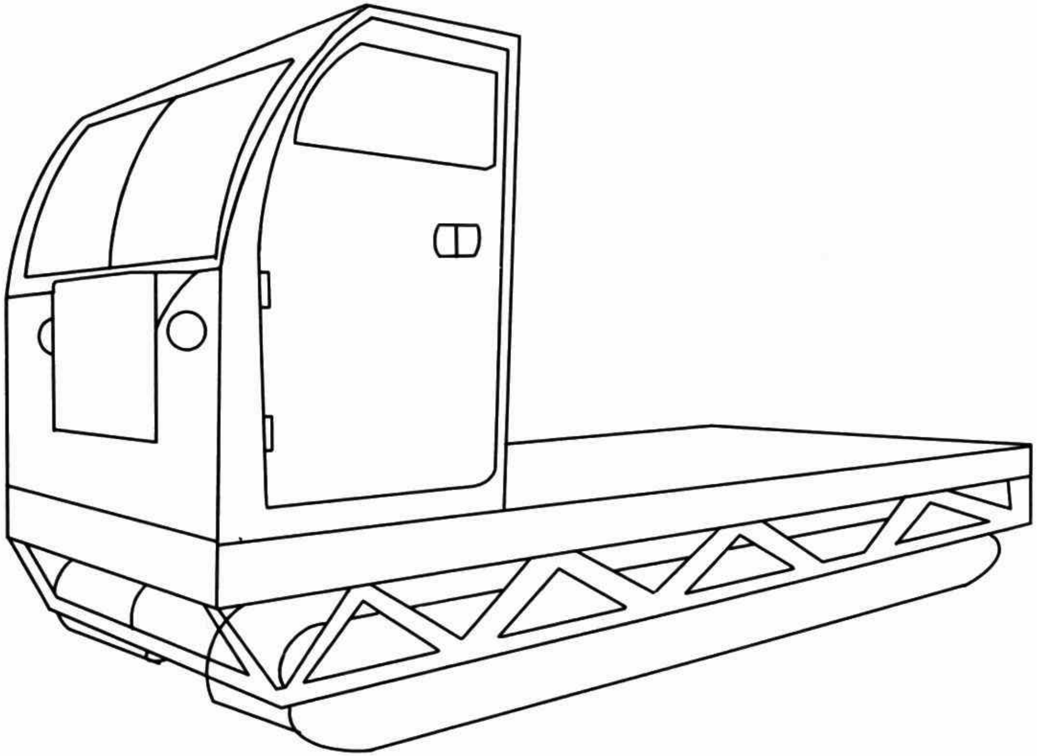
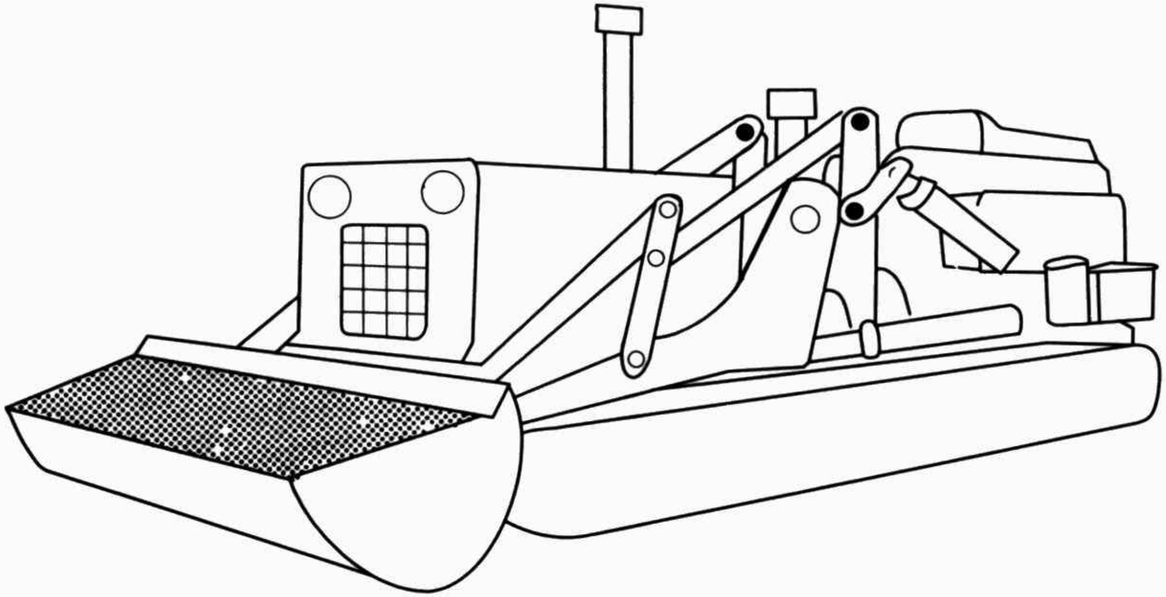


FIGURE 4. ALL-TERRAIN VEHICLE



Make: Caterpillar
Model No. 920
Year of Manufacture: 1972

FIGURE 5. CRAWLER BULLDOZER

Make: Caterpillar
Model No. 955
Year of Manufacture: 1958

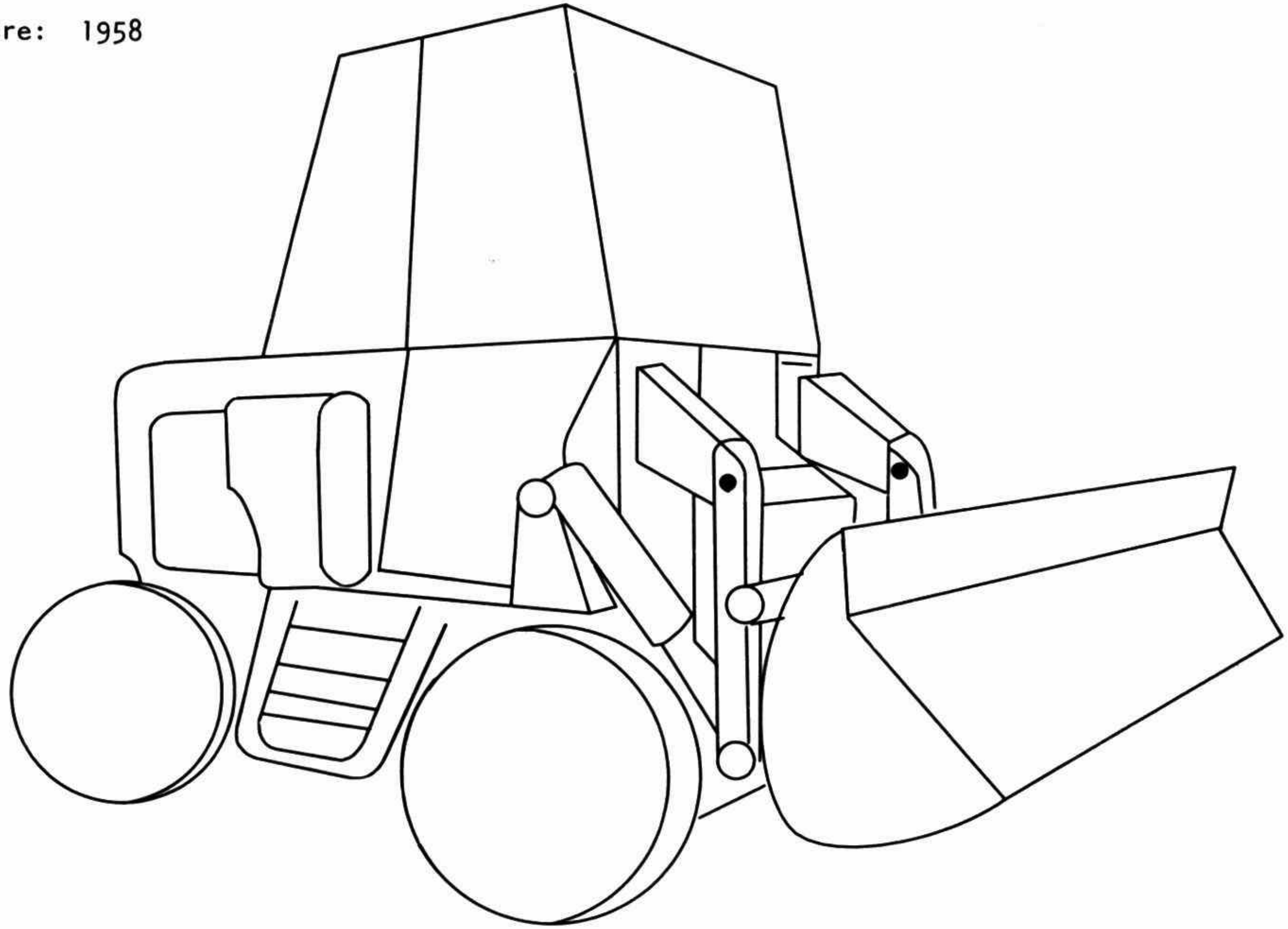


FIGURE 6. FRONT-END LOADER

Under ideal conditions fairly even spreading was accomplished with a normal spraying radius of 75 - 80 feet. The pumping rate was about 250 gpm.

Additional details on the sprinkler system used are found in Appendix II.

5.4 Sludge Application

5.4.1 Particulars

The details on amount of sludge spread, time to spread, the spreading rate and the date and origin of the sludge are shown on Table 7.

5.4.2 Tank truck

As expected, the tank truck became inoperative due to the soft field conditions. To free the tank truck, a tow truck was called in, but it too became mired in the soft soil. Eventually, by the use of winching, the vehicles pulled each other out. A two-and-a-half hour delay was incurred by the above situation. Conditions of this sort would normally preclude the spreading of sludge. Figure 7 shows Plot 1 during sludge application.

5.4.3 All-terrain vehicle

When the ATV was used, the spreading was accomplished uninterrupted by breakdown. There were 15 different tank loads spread. Each time the tank needed refilling it was necessary to drive the ATV to the truck where more sludge was pumped in. This was done to prevent the tank truck from becoming mired. If a full scale operation were set up, a larger tank would be required on the ATV. Figure 8 shows Plot 2 during sludge application.

5.4.4 Injector

Before sludge application was even begun with the injector, the vehicle bogged down in a soft spot while entering the test site and became inoperative. While in operation, the ploughing apparatus frequently plugged up with sod and dirt. It was necessary to stop the operation and chisel away the obstruction with a shovel. At one point, the valve on the injector had to be cleared of wire and rags contained in the sludge. Figure 9 shows Plot 3 during sludge application.

An attempt was made to use the injector in applying sludge to frozen soil. (It was estimated that on the particular day there was 6" - 12" of frost in the ground.) It was decided to simply run the

TABLE 7. SLUDGE APPLICATION DATA

Date	Plot No.	Vehicle	Amount of Sludge Spread	Time Taken	Rate of Application	Origin of Sludge
Nov. 1, 1973	1	Tank Truck	1,200 Imp gal	5 min	240 gal/min	East Port Colborne Pollution Control Plant
Nov. 2, 1973	2	All-terrain Vehicle	3,300 Imp gal	240 min	13.8 gal/min	East Port Colborne Pollution Control Plant
Nov. 5, 1973	3	Sludge Injector	3,000 Imp gal	45 min	66.5 gal/min	West Port Colborne Pollution Control Plant
Nov. 8, 1973	4	Crawler Bulldozer	2,000 Imp gal	210 min	9.5 gal/min	West Port Colborne Pollution Control Plant
Nov. 9, 1973	5	Front-end Loader	3,000 Imp gal	150 min	20 gal/min	West Port Colborne Pollution Control Plant
Jan. 22, 1974	6	Sludge Injector	None	Nil	Nil	West Port Colborne Pollution Control Plant

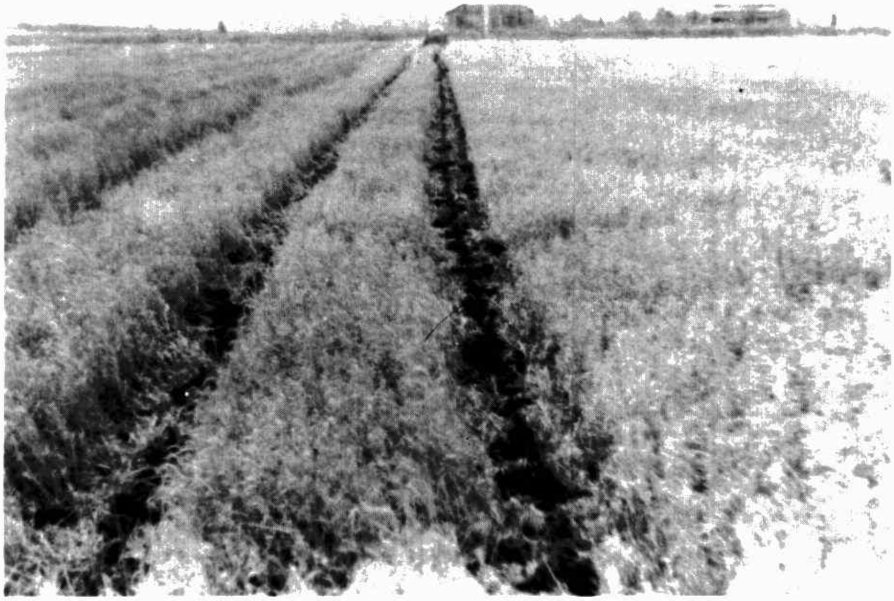


FIGURE 7. PLOT 1 DURING SLUDGE APPLICATION BY TANK TRUCK (NOVEMBER 1, 1973)

FIGURE 8. PLOT 2 DURING SLUDGE APPLICATION BY ATV (NOVEMBER 2, 1973)

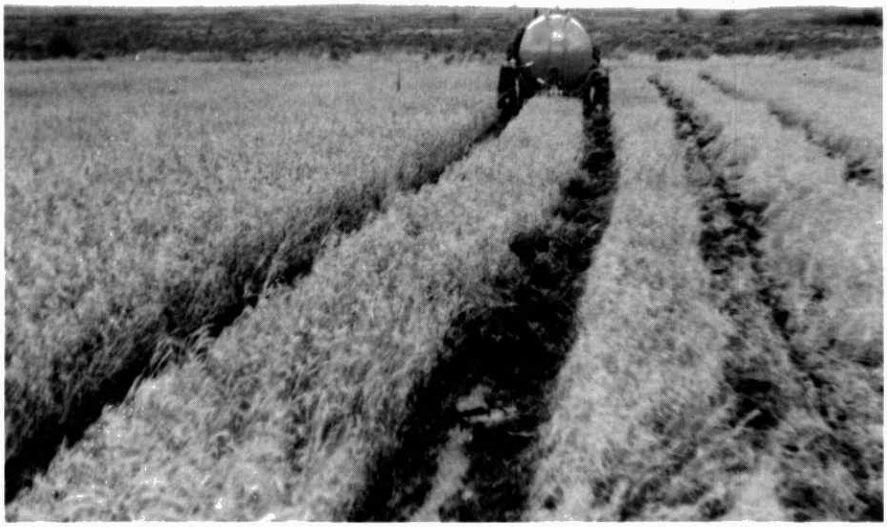


FIGURE 9. PLOT 3 DURING SLUDGE APPLICATION BY SLUDGE INJECTOR (NOVEMBER 5, 1973)

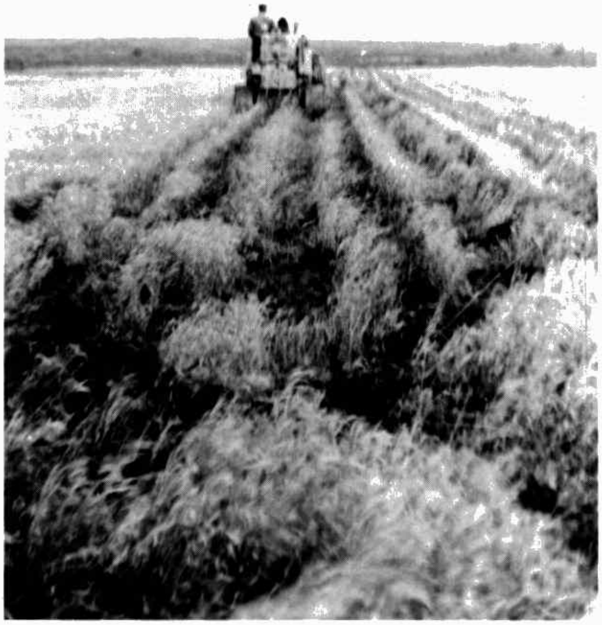


FIGURE 10. PLOT 4 DURING SLUDGE APPLICATION BY CRAWLER BULLDOZER (NOVEMBER 8, 1973)

injector empty to observe whether or not it would function properly. The injector started to open the soil, but after two to three feet, strong resistance was met as the tractor stopped and began spinning its wheels. There was also a considerable build-up of sod and weeds in the ploughing wheels. Actual sludge injection was not attempted as serious damage might have occurred to the injector.

5.4.5 Bulldozer

When the crawler bulldozer was used for sludge spreading no breakdowns occurred. The tank on the bulldozer was loaded by gravity flow from the tank truck. Figure 10 shows Plot 4 during sludge application.

5.4.6 Front-end loader

During the sludge spreading using the front-end loader, there was a slight problem with the two-inch valve on the 250 Imp gallon tank clogging with rags. This obstruction was cleared and the vehicle operated without problems on the wet soil. Figure 11 shows Plot 5 during sludge application.

5.4.7 Sludge spraying

Sludge spraying was demonstrated by a contractor who specializes in sludge disposal. Sludge was sprayed at an approximate rate of 250 Imp gallons per minute. Difficulties were encountered in equalizing sludge distribution to the two heads. This resulted in frequent clogging of the underfed head.

5.5 Discussion

One of the problems sometimes associated with sewage sludge is its odour. However, during each of the sludge applications, no odours attributable to the sludge were detected after spreading.

The compaction test results in Table 2 tend to indicate that Plot 5 (front-end loader) has the least compacting effects. However, the results also show that the wet and dry density of compacted soil is less than the wet and dry density of uncompacted soil for Plot 5. Some error must have occurred in identification or analysis, so these results should not be considered. Compaction results also indicate that the tank truck has less compaction effect than the ATV. This, however,

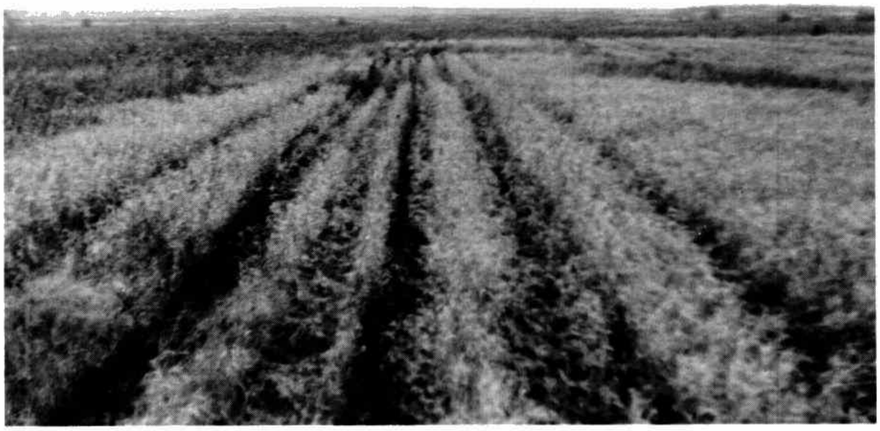


FIGURE 11. PLOT 5 DURING SLUDGE APPLICATION BY FRONT-END LOADER (NOVEMBER 9, 1973)

FIGURE 12. RUTTING IN PLOT 1 (JULY 19, 1974)

is contradictory to what might be anticipated. Rutting in the various plots is shown in Figures 12, 13, 14 and 15.

The only problem encountered with sludge composition was clogging of valves due to large items such as rags and wires. These factors do not show up in Table 1. Therefore, other than for these large items, sludge composition had no effect on the study vehicles. The sludge analysis results will be of use in determining rate of application and effect on soil composition.

Difficulties arose in the sludge spraying for two reasons - weather and sludge composition. If the sludge spraying system is inoperative for more than 30 minutes, the pipes will freeze in temperatures below 32°F (0°C). If sludge contains metal objects and or/matty material, this tends to clog the pump. Also, on windy days, the fine droplets in the spray result in a black mist which is taken away by wind. These conditions are undesirable and cause shutdowns of the operation.

If the difficulties associated with sludge spraying could be overcome, it would be by far the most effective and suitable method for land application of digested sewage sludge.

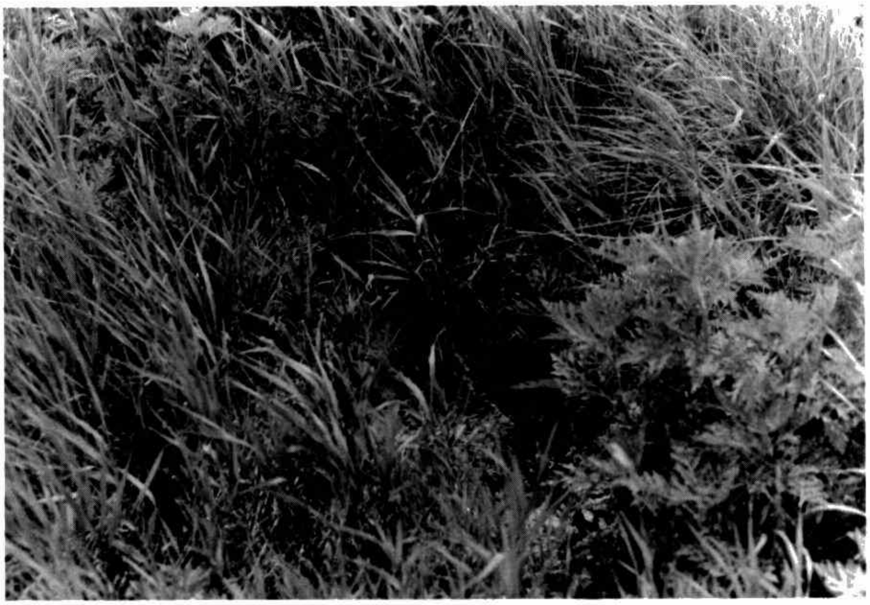


FIGURE 13. RUTTING IN PLOT 2 (JULY 19, 1974)

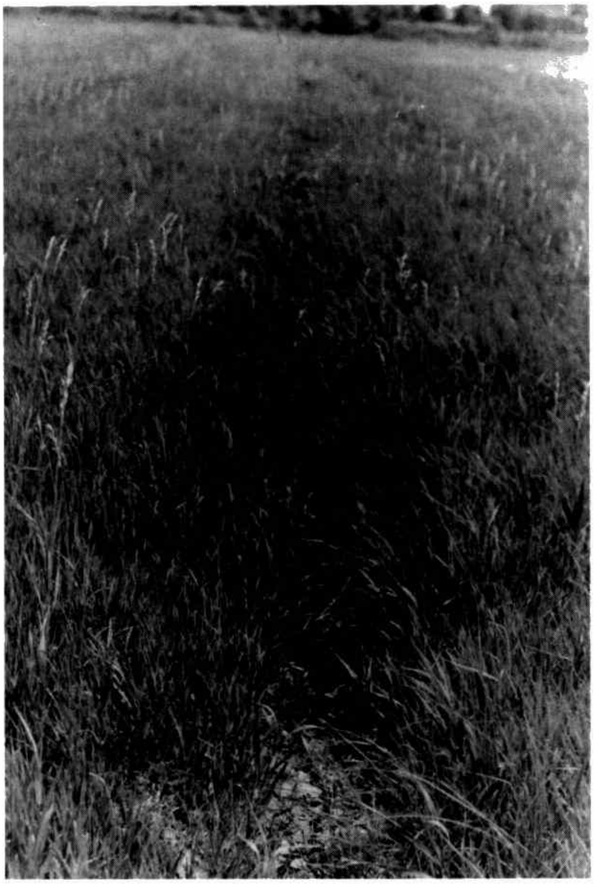


FIGURE 14. RUTTING IN PLOT 3 (JULY 19, 1976)

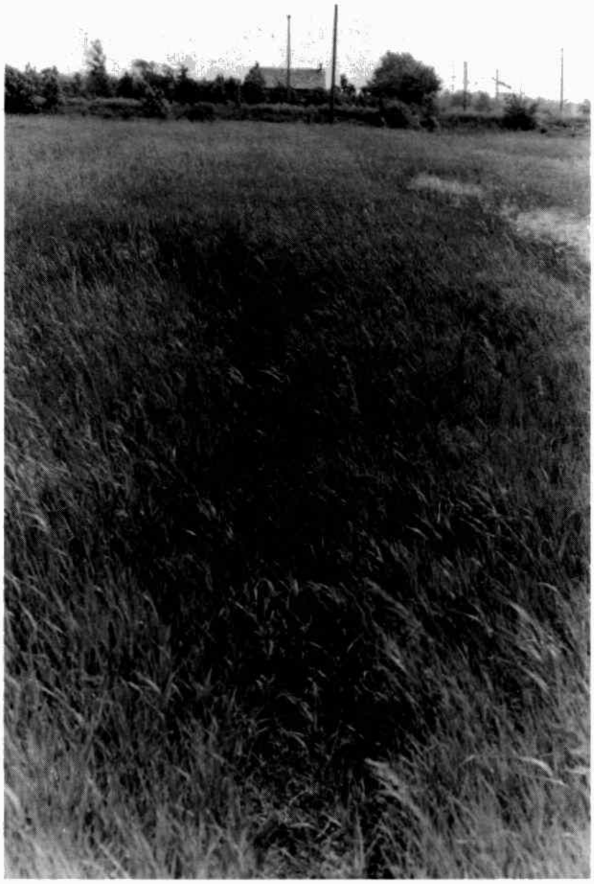


FIGURE 15. RUTTING IN PLOT 4 (JULY 19, 1974)

6. CROP ANALYSIS REPORT

6.1 Introduction

Crop analysis was begun in the middle of June of 1974. Test sites were chosen to be representative of each plot. Five test sites were chosen per plot and five test sites were used for control. In all, thirty test sites, each having an area of one square foot, were used for the study.

The location of each test site is recorded in Figure A8. Figures 16 and 17 show photographs of typical test sites. The samples were obtained by staking each test site as accurately as possible to an area of one square foot. In order to avoid subjecting crop data to statistical analyses, each test site was not chosen randomly, but as being representative of either the compacted or uncompacted area. The grass height was then measured and recorded as grass growth. The test site was then sheared one inch above the ground and the grass accumulated and stored in a plastic bag. Comments on plant distribution and general test site appearance were recorded.

The samples were then air-dried in the sun and weighed for dry weight. This procedure was carried out on three different occasions: the first on June 12th, the second on July 11th and the last on August 9th. The drying period was different on each sampling occasion. The moisture content of the first grass samples was very high, and approximately two weeks were required for drying. For the second and third samplings the drying period was reduced to approximately three days.

The results of these tests are shown in Tables 8 and 9 and are illustrated, graphically, in Figures A9 and A10.

6.2 Discussion

The results of crop analysis indicated that Plot 1, in which the tank truck was used, appeared to have minimal field damage. The samples taken from this plot had an average dry weight of 20.1 grams and an average plot growth of 21.3 centimeters, placing the tank truck with the sludge injector as producing the least field damage. A visual inspection of the plot showed the undesirable effects of the tank truck. The soil was found to be very hard in the ruts when staking of the test sites in this plot was attempted

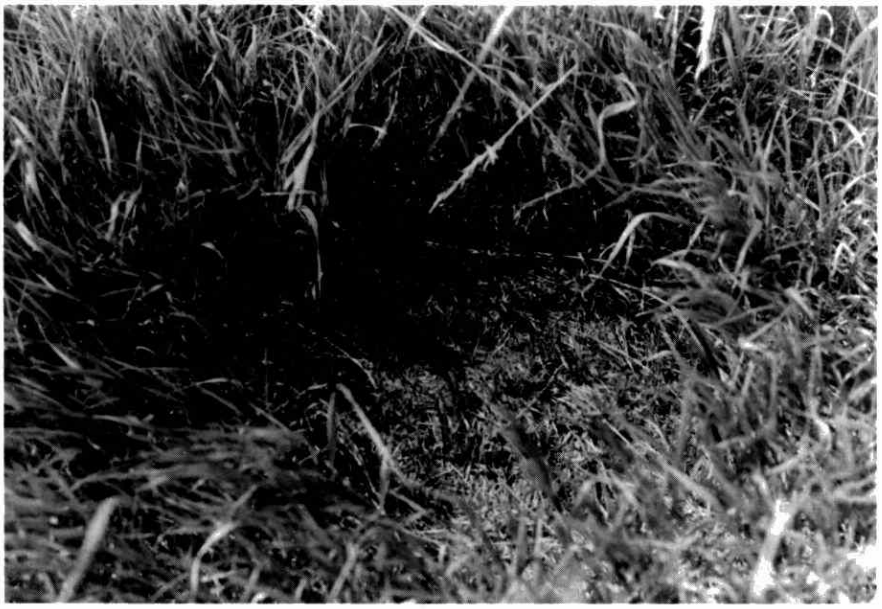


FIGURE 16. TYPICAL CROP ANALYSIS TEST SITE IN UNCOMPACTED SOIL (JULY 19, 1974)

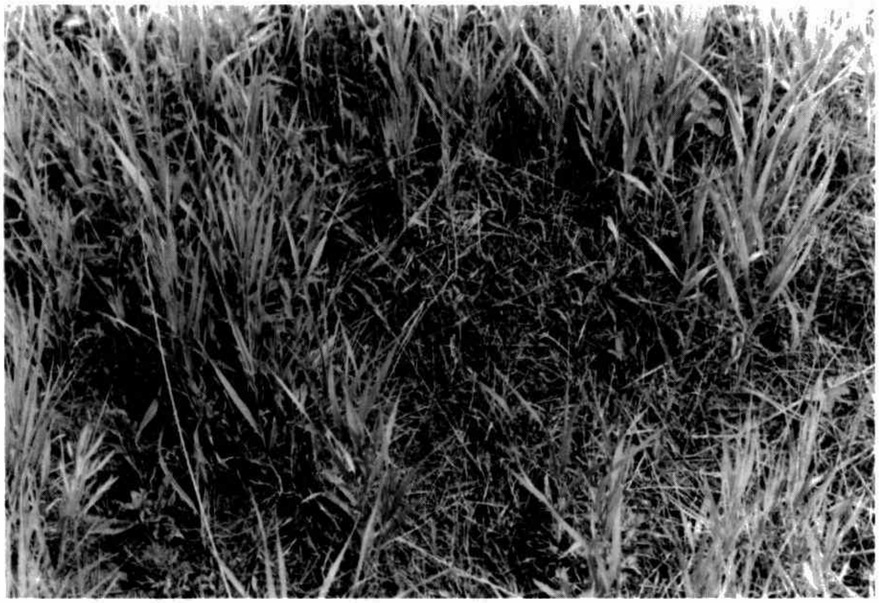


FIGURE 17. TYPICAL CROP ANALYSIS TEST SITE IN COMPACTED SOIL (JULY 19, 1974)

TABLE 8. PLOT SUMMARIES OF TOTAL AVERAGE GROWTH

Plot No.	Vehicle	Average Dry Weight	Maximum Dry Weight	Minimum Dry Weight	Average Plant Growth	Maximum Plant Growth	Minimum Plant Growth
1	Tank Truck	20.1 g	47.4 g	7.3 g	21.3 cm	50.8 cm	5.1 cm
2	All-terrain Vehicle	18.9 g	55.7 g	9.2 g	19.6 cm	53.3 cm	5.1 cm
3	Sludge Injector	20.1 g	41.0 g	5.8 g	21.3 cm	43.2 cm	5.1 cm
4	Bulldozer	18.3 g	61.1 g	4.4 g	18.5 cm	50.8 cm	5.1 cm
5	Front-end Loader	17.9 g	36.9 g	7.4 g	16.5 cm	50.6 cm	5.1 cm
Control	-	19.6 g	47.8 g	7.9 g	28.2 cm	50.8 cm	7.6 cm

TABLE 9. TEST SITE SUMMARY

Plot No.	Vehicle	C/NC	COMPACTED VS NOT COMPACTED		INDIVIDUAL TEST SITES						
			Average Dry Weight (grams)	Average Plant Growth (cm)	Site No.	Average Dry Weight (grams)	Average Plant Growth (cm)	Maximum Dry Weight (grams)	Minimum Dry Weight (grams)	Maximum Plant Growth (cm)	Minimum Plant Growth (cm)
1	Tank Truck	C	14.0	18.5	1	17.2	18.5	31.5	7.3	40.6	5.1
					2	10.7	18.5	15.7	9.2	40.6	5.1
		NC	24.2	23.2	3	23.7	22.1	41.1	12.5	45.7	10.2
					4	25.0	25.4	42.4	12.1	50.8	5.1
					5	23.9	22.1	47.4	7.4	50.8	5.1
2	All-terrain Vehicle	C	14.4	14.9	1	17.9	17.8	27.4	13.0	35.6	5.1
					2	10.8	11.9	12.4	9.2	20.3	5.1
		NC	21.9	22.9	3	19.3	22.9	30.8	13.5	45.7	7.6
					4	16.9	19.6	30.1	10.1	40.6	7.6
					5	29.5	26.2	55.7	14.2	53.3	7.6
3	Sludge Injector	C	20.0	20.3	1	25.5	20.3	36.0	12.7	35.6	10.2
					2	14.5	20.3	27.3	7.7	35.6	7.6
		NC	20.2	22.1	3	23.0	24.6	33.4	13.5	43.2	10.2
					4	19.5	17.0	41.0	7.2	38.1	5.1
					5	18.1	24.6	36.2	5.8	43.2	10.2
4	Bulldozer	C	8.4	15.3	1	8.5	14.5	16.0	4.4	30.5	5.1
					2	8.2	16.0	12.1	5.7	30.5	7.6
		NC	24.9	20.9	3	22.5	20.3	45.2	10.7	45.7	5.1
					4	25.8	20.3	49.3	13.5	45.7	5.1
					5	26.3	22.1	61.1	5.9	50.8	5.1
5	Front-end Loader	C	16.2	13.1	1	16.3	12.7	28.3	8.7	25.4	5.1
					2	16.0	13.5	33.1	7.4	25.4	5.1
		NC	19.1	18.6	3	18.5	19.6	27.7	11.6	40.6	5.1
					4	18.3	18.5	33.8	9.2	38.1	5.1
					5	20.5	17.8	36.9	12.0	38.1	5.1
	CONTROL	NC	19.6	28.3	1	13.9	27.9	20.7	7.9	50.8	7.6
					2	25.5	25.4	47.8	10.3	50.8	7.6
					3	22.7	29.7	45.3	11.2	50.8	10.2
					4	22.9	29.7	46.6	9.6	50.8	10.2
					5	12.8	28.7	19.8	8.8	50.8	10.2

and crevices from drying were very numerous. The tank truck became easily mired and thereby caused excessive rutting. In the particular area where the tank truck became mired, deep ruts were evident where the vegetation had been displaced by the truck wheels, and grass growth in these ruts was nonexistent.

The all-terrain vehicle was used on Plot 2. The samples taken from this plot had an average dry weight of 18.9 grams and an average plant growth of 19.6 centimeters, indicating considerable field damage did occur as a result of the all-terrain vehicle.

From an analysis of the crop results, the sludge injector used on Plot 3 produced very little field damage. The samples taken from this plot had an average dry weight of 20.3 centimeters, the highest figure for the group. Upon inspection of the plot, mounds of soil were still in evidence where the injector had cut its furrow. These were the only visible signs left by the injector.

A crawler bulldozer was used on Plot 4. The samples taken from this plot had an average dry weight of 18.3 grams and an average plant growth of 18.5 centimeters, indicating considerable field damage. The ground was very hard upon attempting penetration during staking of the test sites in this plot. Cracks and crevices were numerous in the plot.

The front-end loader was used on Plot 5. The samples taken from this plot had an average dry weight of 17.9 grams and average plant growth of 16.5 centimeters. These results were the lowest of the group and indicate excessive field damage. This plot was characterized by many different types of weeds. Effects of the testing were noticeable irregularly across the test area; these were particularly evident where vehicles had travelled. Grass had grown over all this test site except in the deep ruts caused by the tank truck when it became mired. Grass growth was visibly inhibited in compacted soil (i.e. where vehicle wheels and tracks had travelled). Figures 18 to 22 show general views of the five test plots.

In conclusion, the sludge injector was judged as causing the least field damage. The tank truck, which was the conventional vehicle, did well in the results, indicating that despite the inherent problems normally associated with its use, it is still a practical vehicle for this purpose when compared to the other test vehicles.

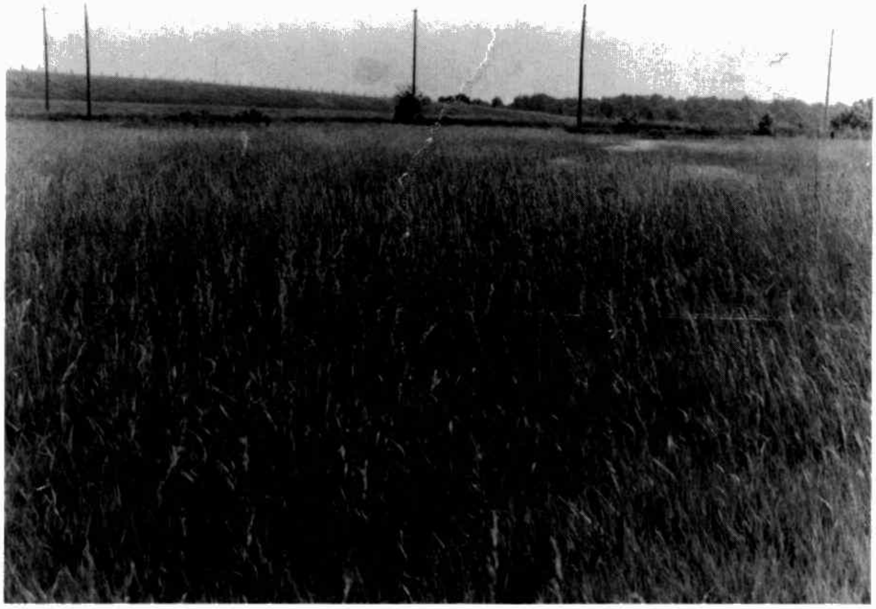


FIGURE 18. GENERAL VIEW OF PLOT 1 (JULY 19, 1974)

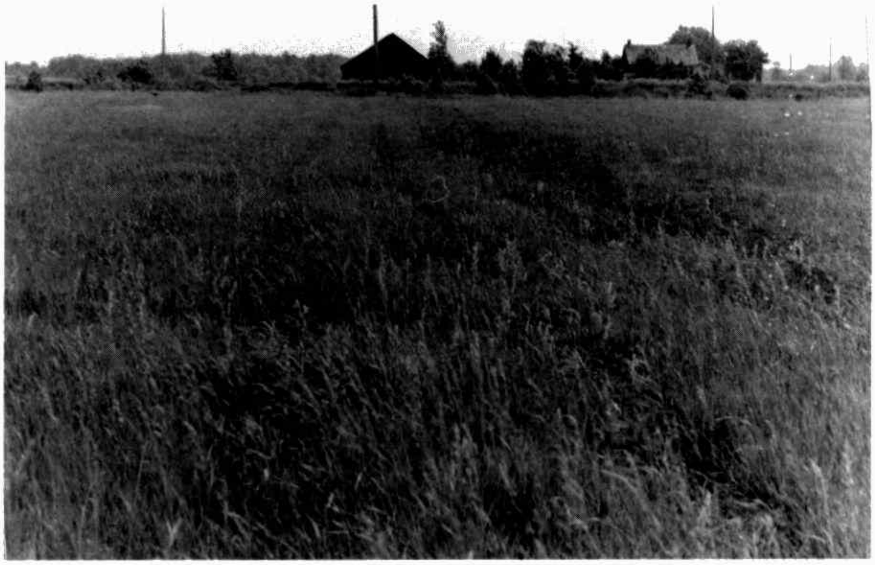


FIGURE 19. GENERAL VIEW OF PLOT 2 (JULY 19, 1974)

FIGURE 20. GENERAL VIEW OF PLOT 3 (JULY 19, 1974)

FIGURE 21. GENERAL VIEW OF PLOT 4 (JULY 19, 1974)

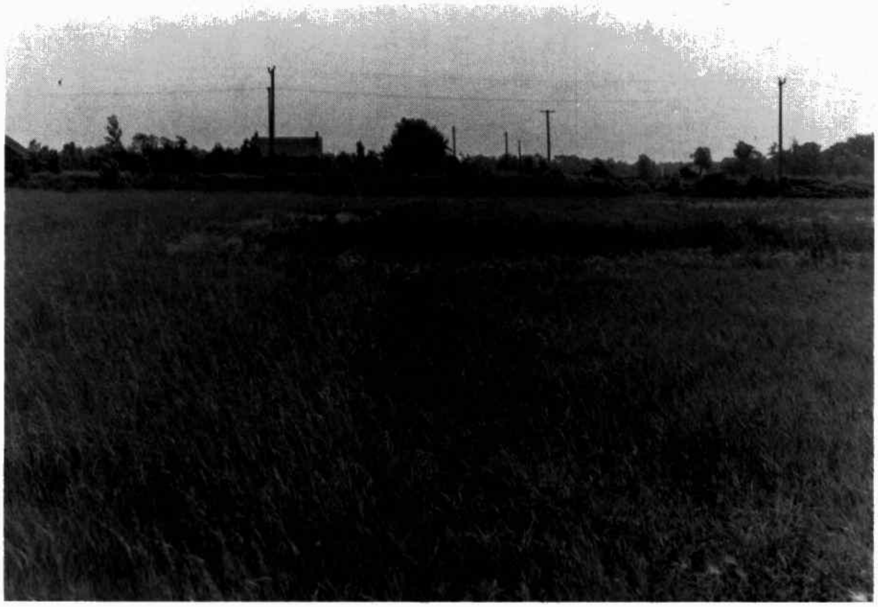


FIGURE 22. GENERAL VIEW OF PLOT 5 SHOWING THE DIFFERENT TYPE OF VEGETATION OCCURRING IN THE MIDDLE PORTION OF THE PLOT (JULY 19, 1974)

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APPENDIX I

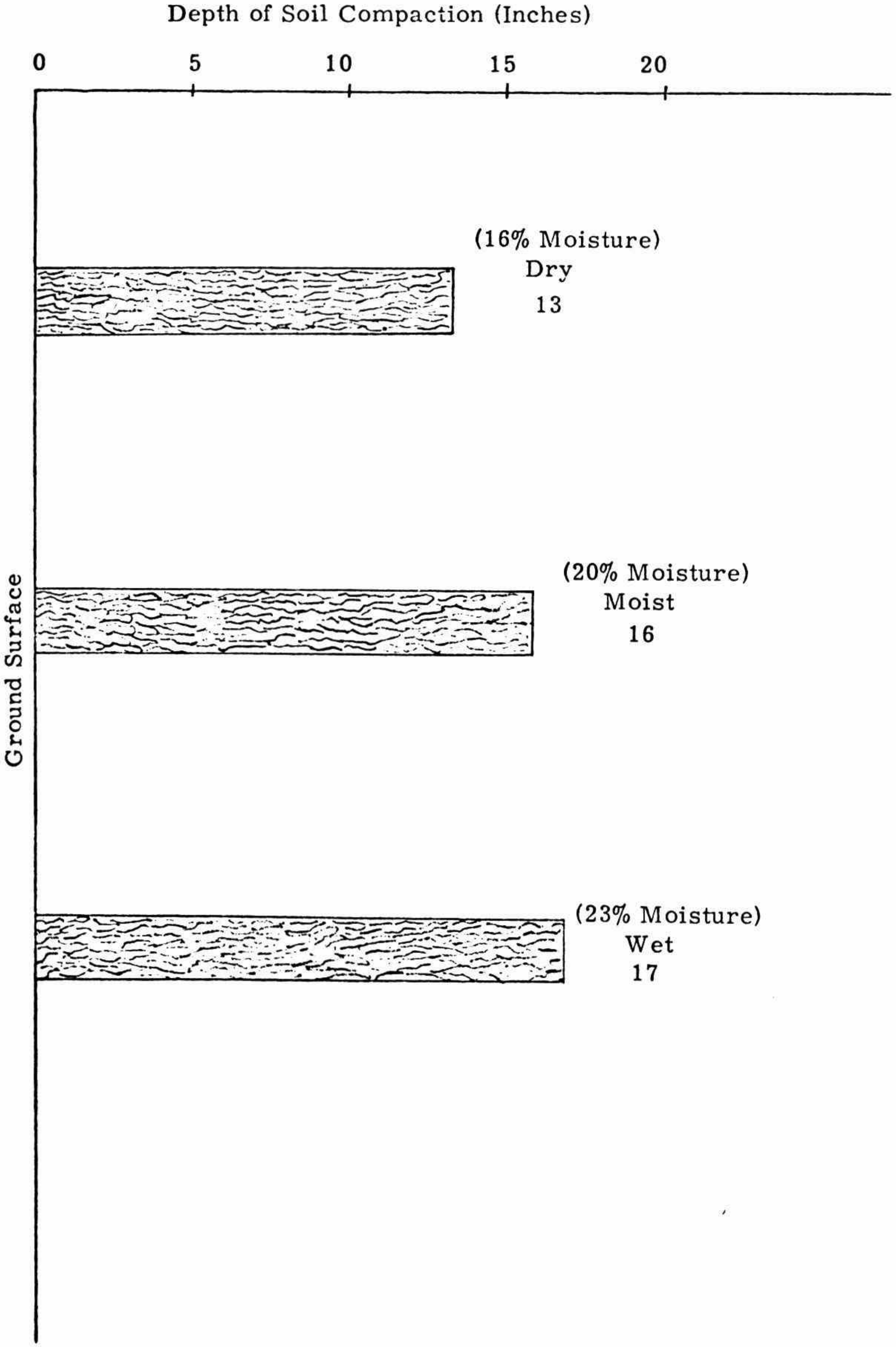


FIGURE A1. DEPTH OF COMPACTION vs. SOIL MOISTURE CONTENT

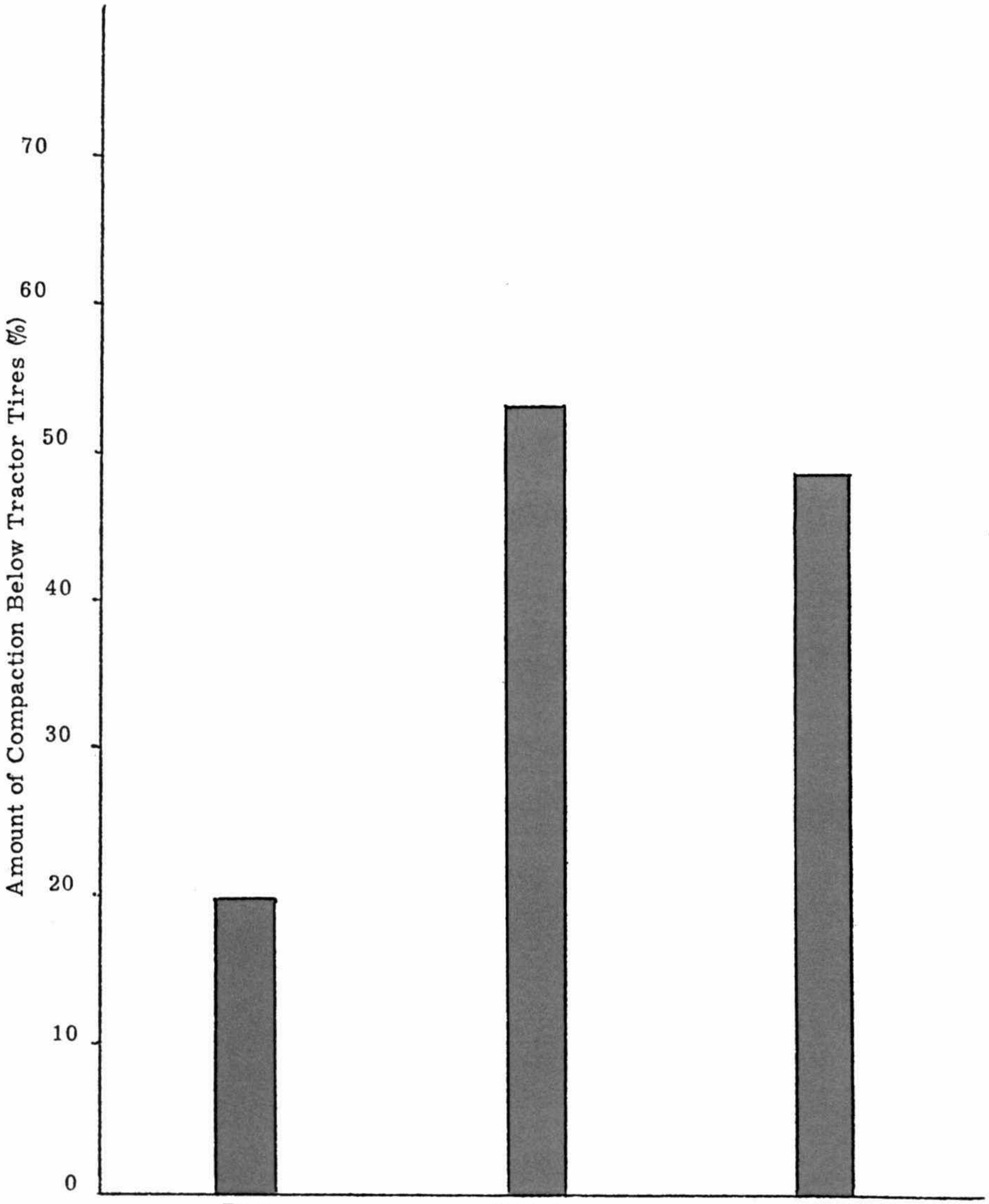
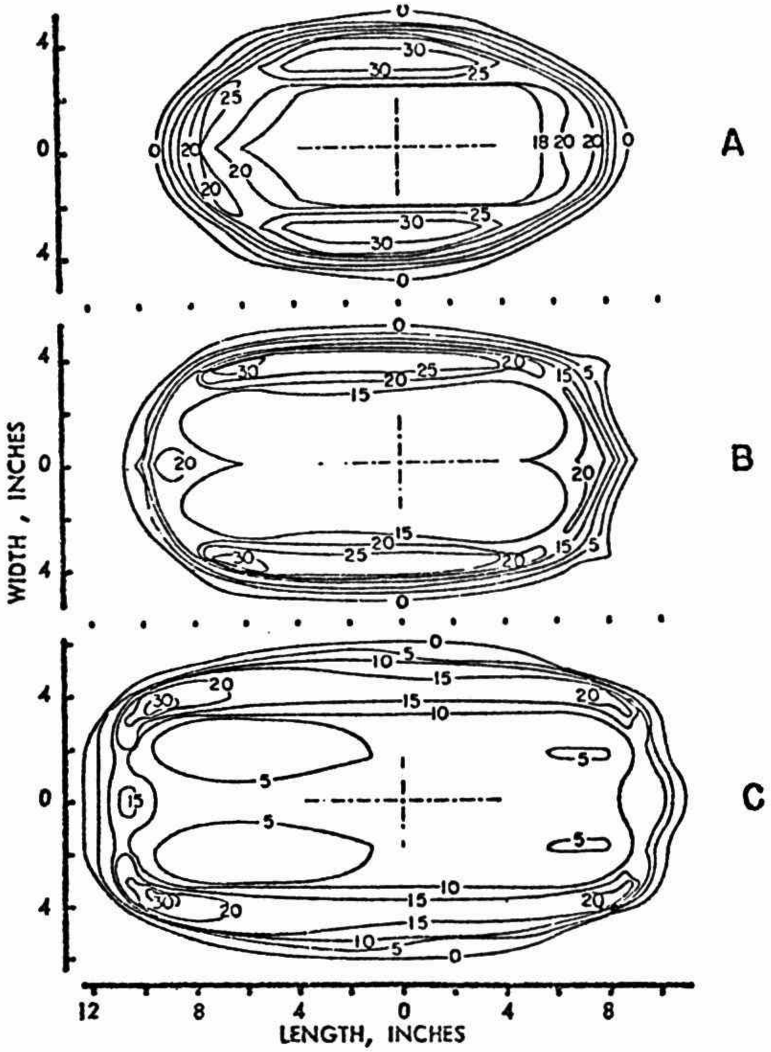


FIGURE A2. SOIL COMPACTION vs. SOIL MOISTURE CONTENT



Pressure distributions under a smooth 11-38 rubber tire moving over firm sand when inflated: A, to 14 psi; B, to 10 psi; C, to 6 psi. The direction of travel was toward the left. (Vanden Berg and Gill, 1962)

FIGURE A3. TIRE PRESSURE DISTRIBUTIONS ON SOIL

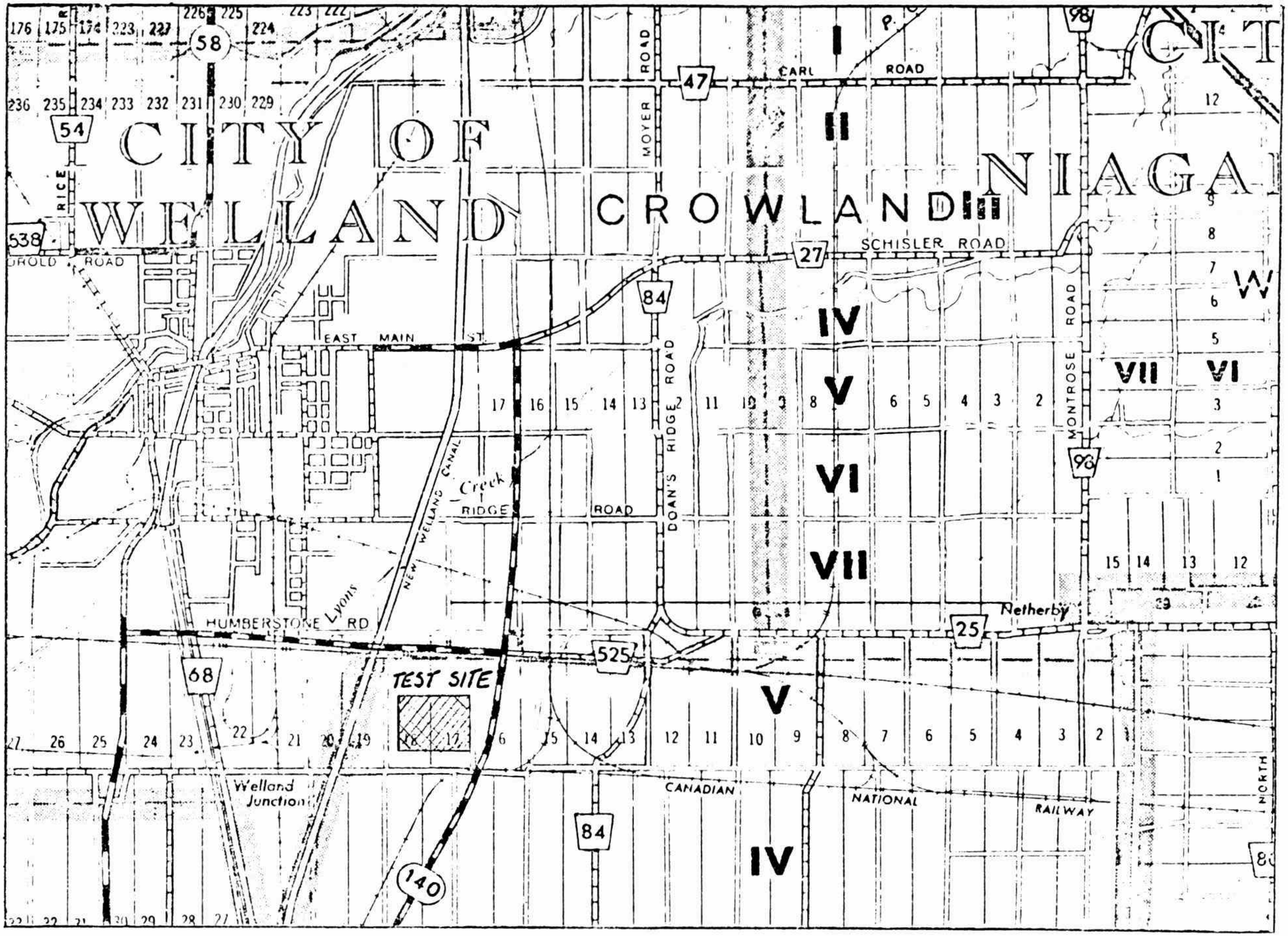


FIGURE A4. LOCATION OF TEST SITE

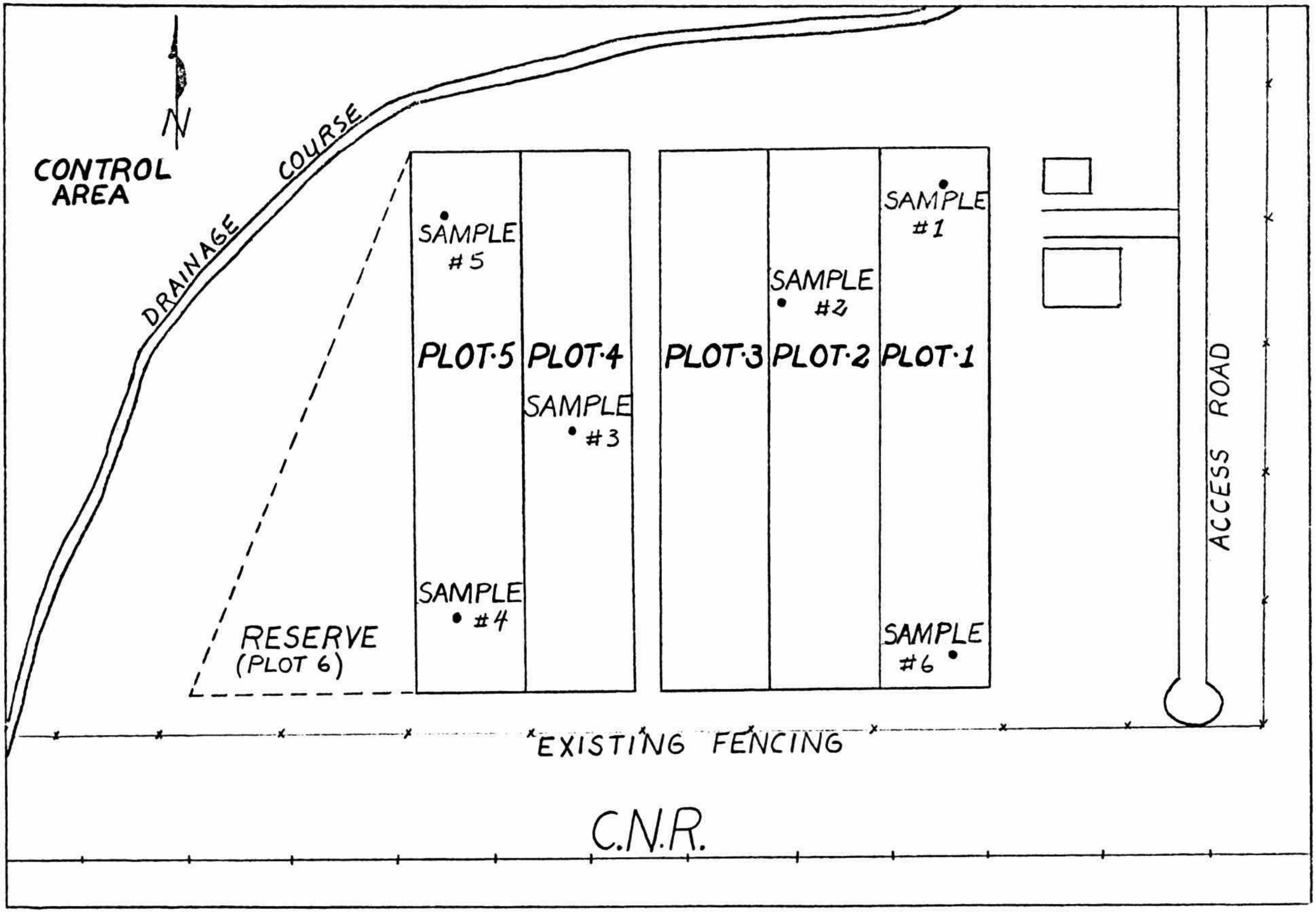


FIGURE A5. LOCATION OF SOIL ANALYSIS SITES

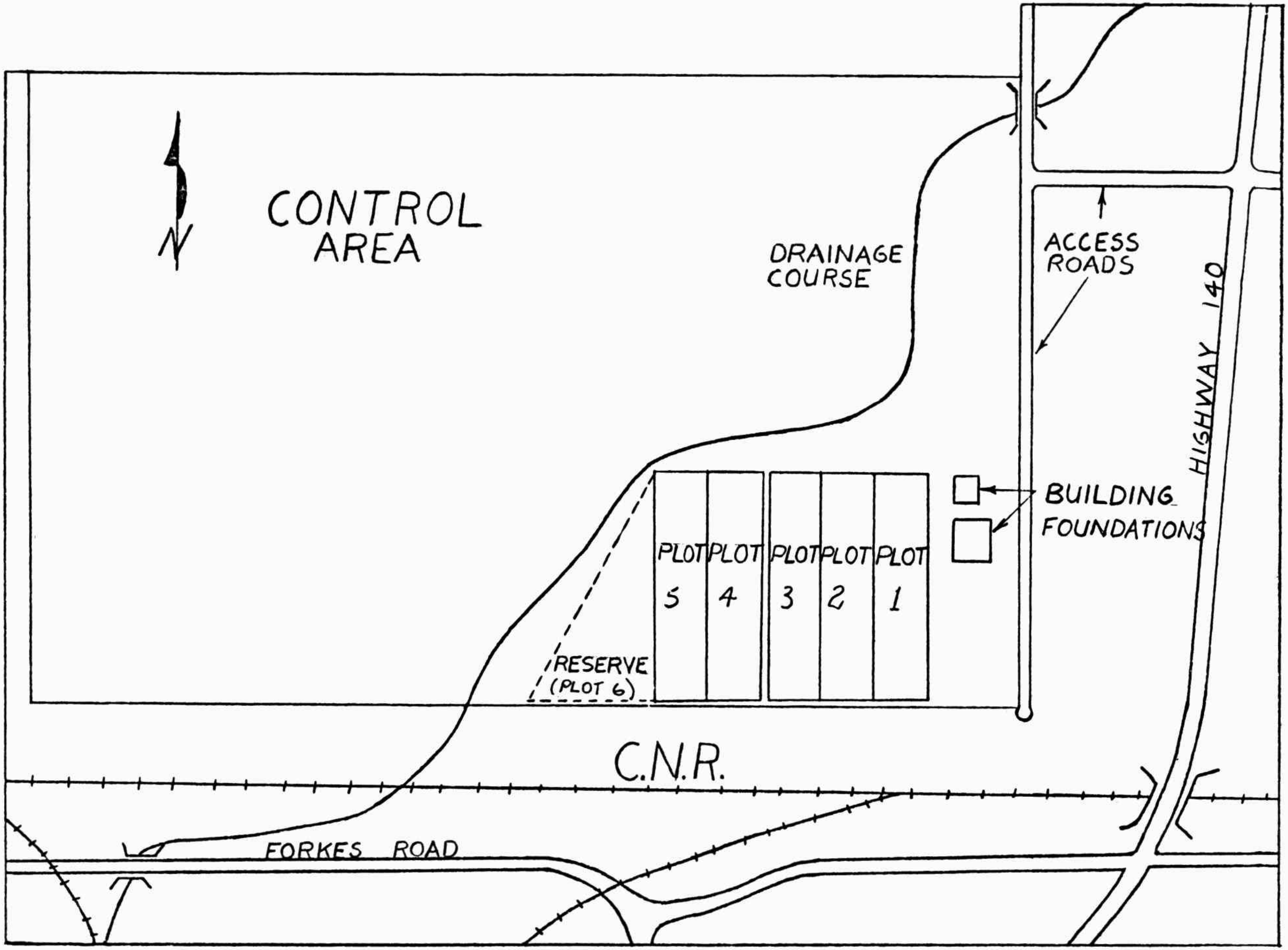


FIGURE A6. TEST SITE LAYOUT

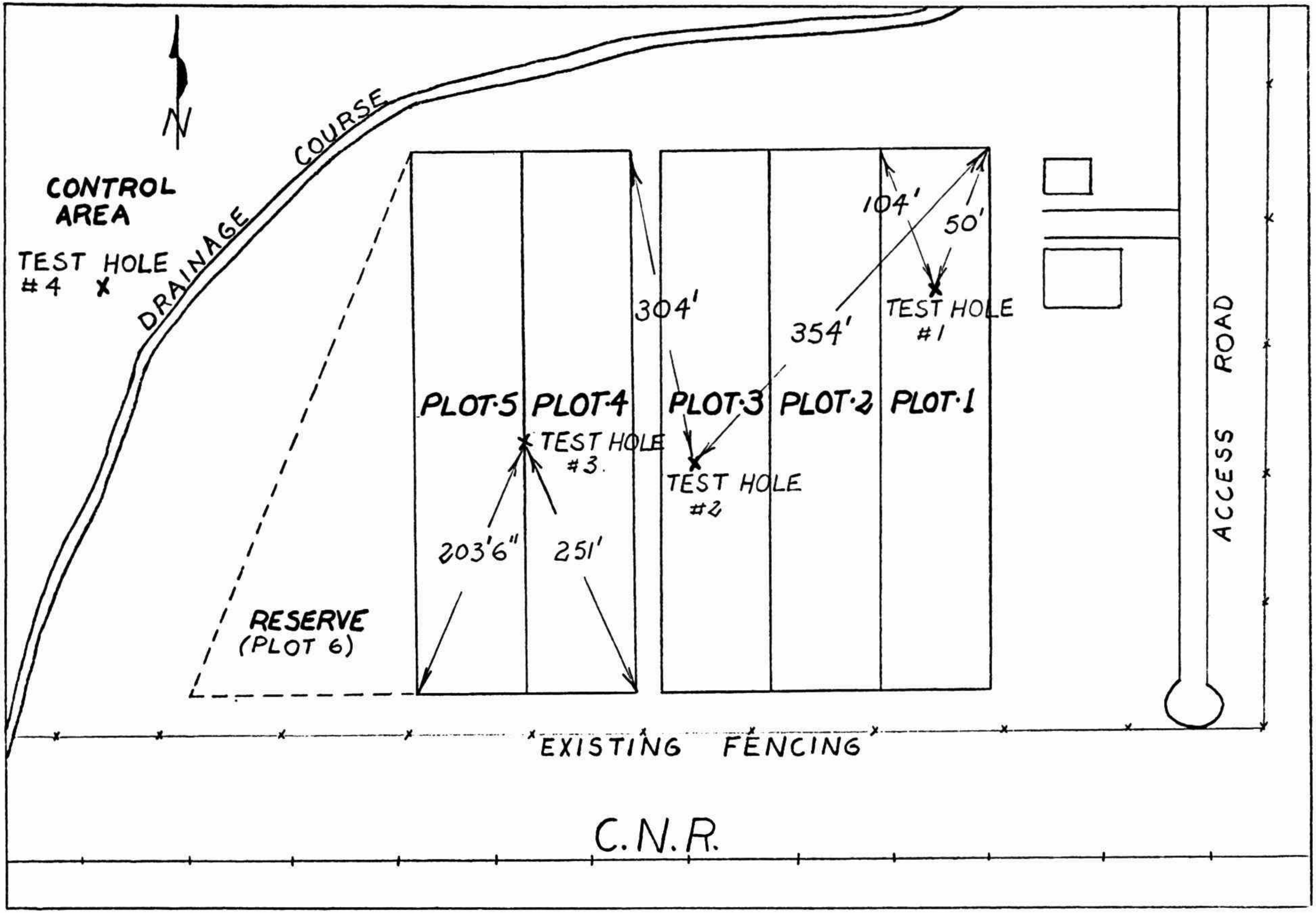


FIGURE A7. LOCATION OF DRILLING SITES FOR TEXTURAL CLASSIFICATION

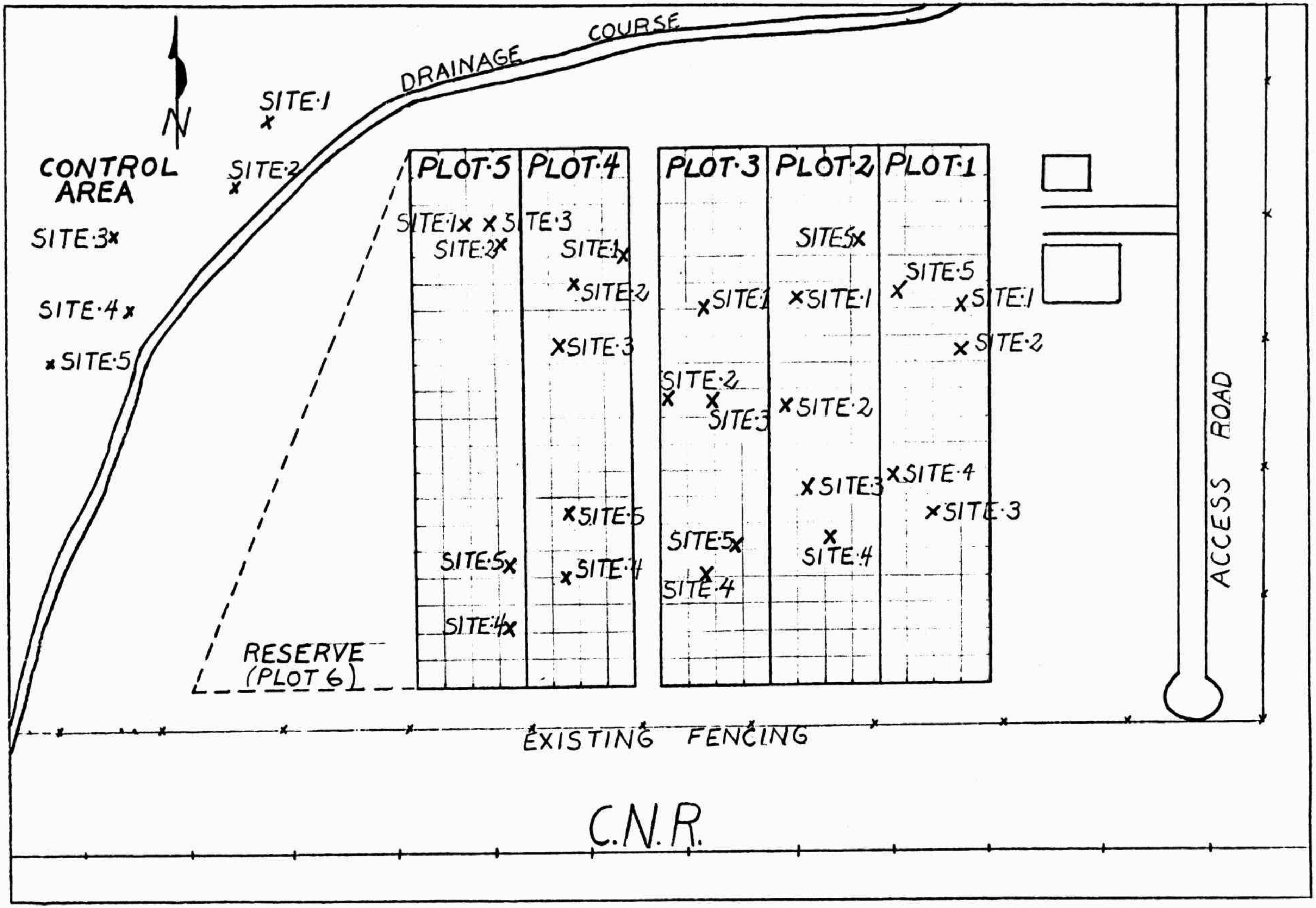


FIGURE A8. LOCATION OF CROP ANALYSIS SITES

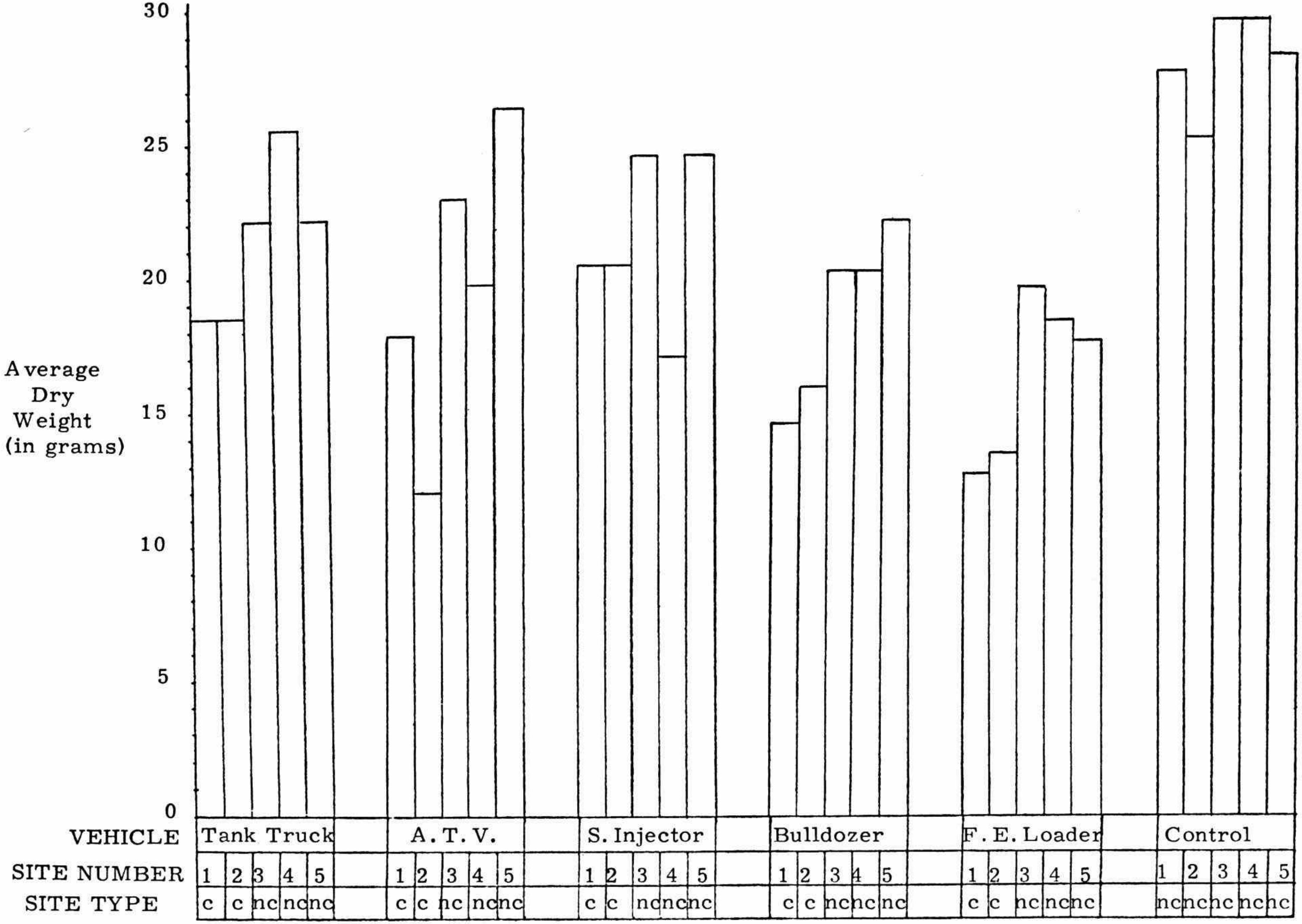


FIGURE A9. AVERAGE DRY WEIGHT vs. TEST SITE

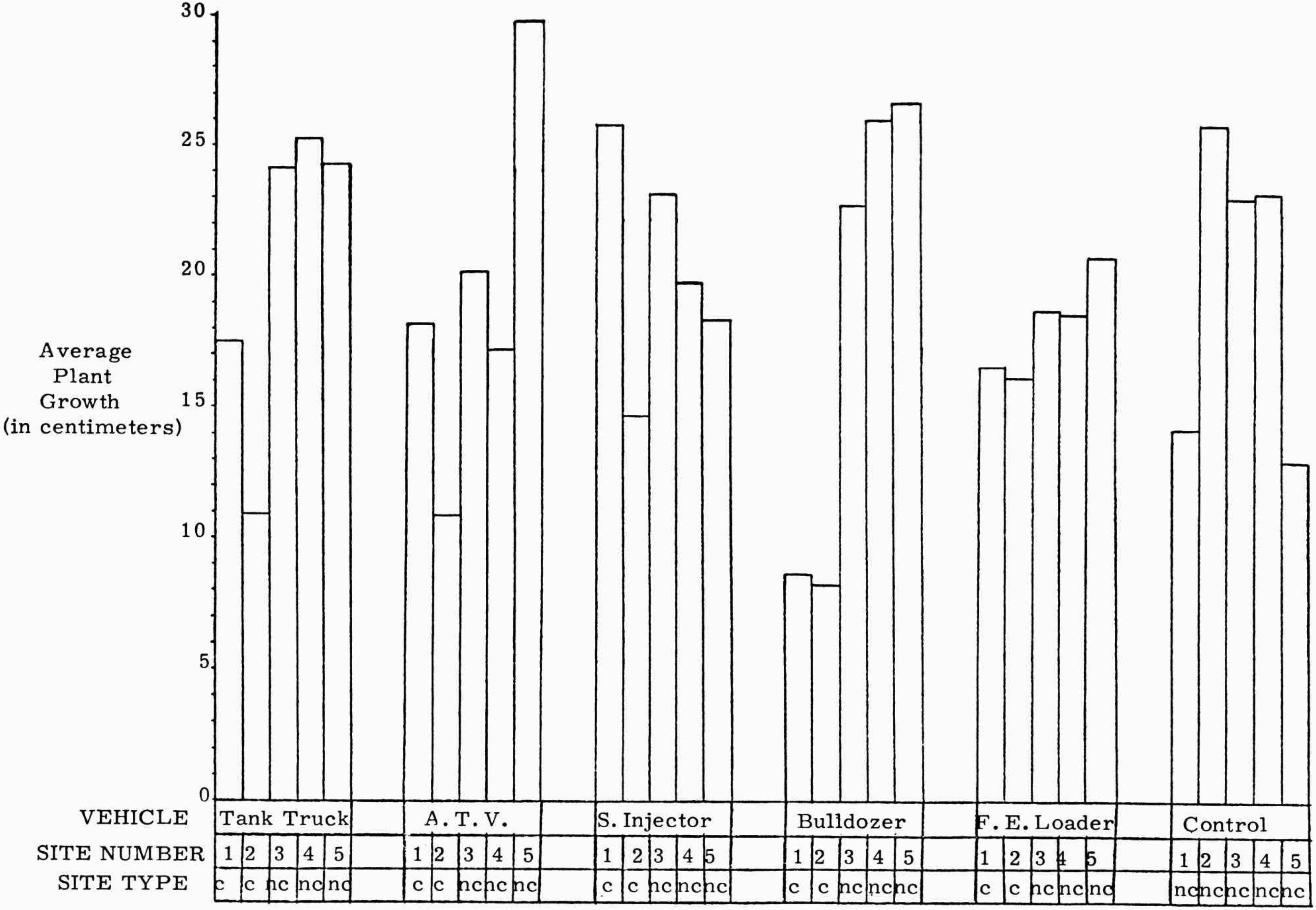


FIGURE A10. AVERAGE PLANT GROWTH vs. TEST SITE

TABLE A1. Weather Data for January, 1974
Niagara District Weather Office
(St. Catharines, Ontario)

Lat: 43° 11' Long: 79° 11' Elevation: 324 feet. Standard Time Used: Eastern

Date	Temperature (°F)			Degree Days below 65°F	Relative Humidity (%)				Wind (M.P.H.)			Duration of Bright *Sunshine (hours)	Growing Degree Days above 42°
	Maximum	Minimum	Mean from Max and Min						Average Speed	Prevailing Direction	Maximum Speed and Direction		
1	26	10	18	47					11.3	W	W 19	5.5	
2	18	4	11	54					8.4	W	W 12	3.7	
3	26	16	21	44					3.2	SW	W 7	0.0	
4	22	11	17	48					11.5	SW	SW 17	7.3	
5	25	7	16	49					8.8	SW	SW 12	0.6	
6	25	17	21	44					8.6	SW	W 12	0.0	
7	24	11	18	47					16.2	W	W 25	6.4	
8	19	6	13	52					9.4	SW	E 17	7.0	
9	23	13	18	47					10.6	E	E 18	0.4	
10	25	16	21	44					11.6	E	E 15	0.0	
11	23	7	15	50					8.8	SVL	N 15	0.3	
12	20	4	12	53					15.0	W	W 14	4.0	
13	16	1	9	56					10.5	SW	SW 16	7.9	
14	37	14	26	39					18.4	SW	SW 37	4.1	
15	40	28	34	31					12.3	SW	SW 19	0.0	
16	40	22	31	34					14.5	SW	SW 24	0.0	
17	23	8	16	49					18.6	E	E 23	0.0	
18	30	10	20	45					10.5	E	E 24	0.0	
19	31	16	24	41					5.9	N	N 14	7.4	
20	32	17	25	40					10.9	E	E 15	0.0	
21	49	30	40	25					18.1	SW	S 27	0.0	
22	36	32	34	31					8.9	E	W 21	0.0	
23	46	29	38	27					13.7	W	W 19	1.0	
24	38	26	32	33					15.7	SW	SW 25	6.4	
25	41	31	36	29					17.8	SW	SW 28	5.6	
26	52	32	42	23					10.4	S	S 26	5.4	
27	56	37	47	18					24.6	SW	SW 46	0.6	5
28	37	32	35	30					7.9	SW	SW 16	0.0	
29	36	32	34	31					7.5	SW	SW 12	0.2	
30	47	35	41	24					19.3	SW	SW 25	7.3	
31	49	24	37	28					26.0	SW	SW 40	4.6	
Mean	32.6	18.6	25.6	1213 Tot.					12.7	SW Prev.	SW 46 Max.	85.7 Tot.	5 Tot.
Normal	31.4	20.0	25.8	1187								80	

UDC 551.506 (713.38) * from Vineland Station

SVL ... more than one direction. (56)

Table A1 cont'd...

Precipitation (Inches)(1)

Date	Rainfall	Snowfall	(2) Total Precip.	(3) Depth of Snow on Ground
1		1.6	.07	5
2		TR	TR	4
3		TR	TR	3
4		TR	TR	2
5				2
6		.6	.04	2
7		TR	TR	2
8		1.0	.10	2
9		2.4	.22	5
10		.2	.02	5
11		1.2	.11	5
12		.5	.05	5
13				5
14				5
15	.01		.01	2
16	TR		TR	1
17		.8	.02	TR
18	.03		.03	1
19	TR	TR	TR	1
20	.18		.18	TR
21	.12		.12	TR
22	.25	.5	.30	TR
23	.06	TR	.06	
24				
25				
26	.26		.26	
27	.04		.04	
28	TR	3.7	.37	
29	TR	.5	.05	1
30				TR
31	.02	TR	.02	
Total	0.97	13.0	2.07	
Normal	1.07	14.5	2.52	

Daily Weather Summary for January 1974 at St. Catharines

1. Cloudy with morning snow, then clearing and colder after noon.
2. Partly cloudy and very cold. Snow in the afternoon.
3. Cloudy with afternoon snow, not as cold.
4. Cloudy with sunny periods and a few flurries.
5. Cloudy and cold.

6. Overcast over light snow in the afternoon and evening.
7. Snow ending before daybreak then clearing.
8. Sunny and cold. Snow beginning in the evening.
9. Cold with snow, heavy in the morning.
10. Cloudy with light snow.

11. Cloudy with light snow.
12. A few sunny intervals and some light snow.
13. Sunny and very cold
14. Cloudy, windy and mild. Peak gust 49 MPH.
15. Continuing dull and mild with some showers.

16. Overcast and mild. Light freezing drizzle in the evening.
17. Cloudy and much colder. Morning snow.
18. Cloudy with freezing rain in the evening.
19. Mostly sunny and cold.
20. Cloudy with freezing rain throughout the day.

21. Overcast and mild with occasional showers.
22. Cloudy and colder, snow beginning in the afternoon changing to rain in the evening.
23. Rain ending in the early morning then cloudy and mild
24. Sunny, windy and mild.
25. Sunny with a few cloudy periods, windy and mild.

26. Sunny and very mild, becoming cloudy with rain by the evening.
27. Overcast and mild, extremely windy, gust to 67 MPH. Early morning showers.
28. Cloudy and mild with wet snow in the afternoon and evening
29. Snow ending before dawn, then cloudy and mild.
30. Sunny with a few cloudy periods, windy, mild.
31. Turning much colder in the afternoon with brief rainshowers. Flurries after sunset.

Days with Total Precipitation					Days with Snowfall					Thunderstorms		
0.01" or more	0.04" or more	0.25" or more	0.50" or more	1.00" or more	0.1" or more	0.4" or more	2.5" or more	5.0" or more	10.0" or more	No.	Normal	Dates
19	14	2	0	0	11	10	1	0	0	0		

(1) TR=Trace=negligible amount of rain or snow. Precipitation data are based on 24 hour period beginning 1 A.M.

(2) Total precipitation is computed by adding rainfall in inches to water equivalent to the snowfall in inches.

(3) Measurement taken at 7 A.M.

TABLE A2. Monthly Precipitation in 1973

Month	1973 Snowfall	1973 Rainfall	1973 Total Precipitation	Average Precipitation	Average Precipitation
January	33	1.12	1.45	2.3	3.1
February	102	0.69	1.73	1.8	2.9
March	44	3.56	4.08	2.1	2.7
April	8	4.11	4.18	2.4	2.8
May	Nil	2.82	2.82	2.1	2.8
June	Nil	2.61	2.61	2.5	2.7
July	Nil	1.90	1.90	2.4	3.2
August	Nil	0.63	0.63	2.5	2.4
September	Nil	2.72	2.72	2.6	2.8
October	Nil	4.55	2.55	2.2	2.9
November	12	4.25	4.37	2.1	2.6
December	231	2.48	4.42	2.0	2.9
Total	430	31.44	35.46	27.0	33.9
AVERAGE	35.8	2.62	2.96	2.08	2.65

APPENDIX II

SPRINKLERS

The Sprinklers were manufactured by White-Rain Company - British made. These came under the name Manurain, type 50-04. During testing, a 7/8-inch nozzle was used. Additional information was obtained, verbally, from the supplier. This particular sprinkler is rated at 70 lb pressure and 156 Imp gal/min capacity with a No. 14 nozzle. The spraying diameter is rated at, approximately, 175 feet. The sprinklers were obtained through an Ontario outlet of White-Rain Company, Vandendussche Irrigation and Equipment.

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Land application of digested
sludge under adverse conditions /
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